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Paperless mapping and cave archaeology: A review on the application of DistoX survey method in archaeological cave sites

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ABSTRACT

Geodetic Stations and Differential Global Positioning Systems are the dominant instruments for mapping in archaeological contexts. However, there are not equal counterparts for cave archaeology survey. There is no way for DGPSs to work inside a cave and use of geodetic station is limited only in relatively dry and wide parts of the caves. This paper is reviewing the current available applications on cave mapping and it is presenting the use of Heeb's Paperless Mapping technique as a mainstream survey tool for subterranean archaeological projects. Ultimately a step by step methodology is proposed.

1. Cave mapping. Definitions, methodology and techniques

Geodetic stations and Differential Global Positioning Systems (DGPSs) are now widely used as the main application for archaeological mapping. Data are consequently imported to Computer -Aided Design (CAD) or Geographic Information System (GIS) software application to visualize and analyze the archaeological spatial data. But what archaeologists are using when these applications are impossible to be used?

In certain subterranean environments, such as deep, wet, and/or narrow caves the use of geodetic stations is prohibitive – or should be avoided – for a number of reasons. Firstly, the almost extreme humidity (which reaches 99% on many occasions) affects the geodetic stations and makes leads to malfunction in many cases. Raindrops or dripping water very often threatens to affect the functioning of the instrument. Secondly, in cases of narrow passages or very low chambers it is not feasible to set the geodetic station on a tripod and to place it vertically. Thirdly, the geodetic station often has its position changed many times and as such its advantage of high precision in measurements is minimized; also triangulation is very difficult to achieve (see also Moyes, 2002). Many times also archaeologists cannot have geodetic stations available due to the large costs of maintain one or due to the project it does not need the accuracy of such an instrument. In open-air sites GPSs covered these occasions but in caves, where GPSs are useless other methods need to be applied.

Until the beginning of 2011 the dominant way of mapping a cave and its finds that can be found in literature was the traditional one, including a compass and a tape (or Electronic Distance meters (EDM)) (Stratford, 2011). In this case the measurements are recorded by hand and are transported to the database. The mapping error rate in this case is quite large although the results of this method whenever it was applied were satisfactory (e.g. see Moyes, 2002; Stratford, 2011). Over recent years there have been reliable solutions for cave mapping that cost less than geodetic stations, are more user-friendly, without adaptation problems for the cave-environment and provide equally accurate measurements to a total station if the correct methodology is followed.

It is imperative that cave mapping and its characteristics be defined before further analysis. Cave mapping is defined in literature in two distinct ways; either as a survey or as mapping (see Tarsoly, 2006). Both terms are equally acceptable. As this paper deals with archaeological data, the term "mapping" will be used due to the fact that surface field research is characterized often as "survey" in archaeological research.

A prerequisite for the success and accuracy of a mapping is the cave itself. The complexity of the space does not allow researchers to fully grasp the actual size of the dimensions. Nevertheless, the process of cave exploration as well as its systematic study requires the existence of an exhaustive and reliable background in an appropriate form and scale that responds to all the cognitive fields (Kalogeropoulos et al., 2008). The mapping process is hindered by various factors, of which two are the most important. Firstly, the cartographer does not always work in ideal conditions because the particular environment is characterized by darkness, humidity, cold, etc. (Doggouris et al., 1986). As a result, mapping becomes challenging. Secondly, the complexity of the cave necessitates the mapping of parts that are situated on completely different levels. Consequently, the recording of information for a three-dimensional space is required.

The traditional mapping method includes the data collection about the map, that is to say the measurements from a mapping group in the

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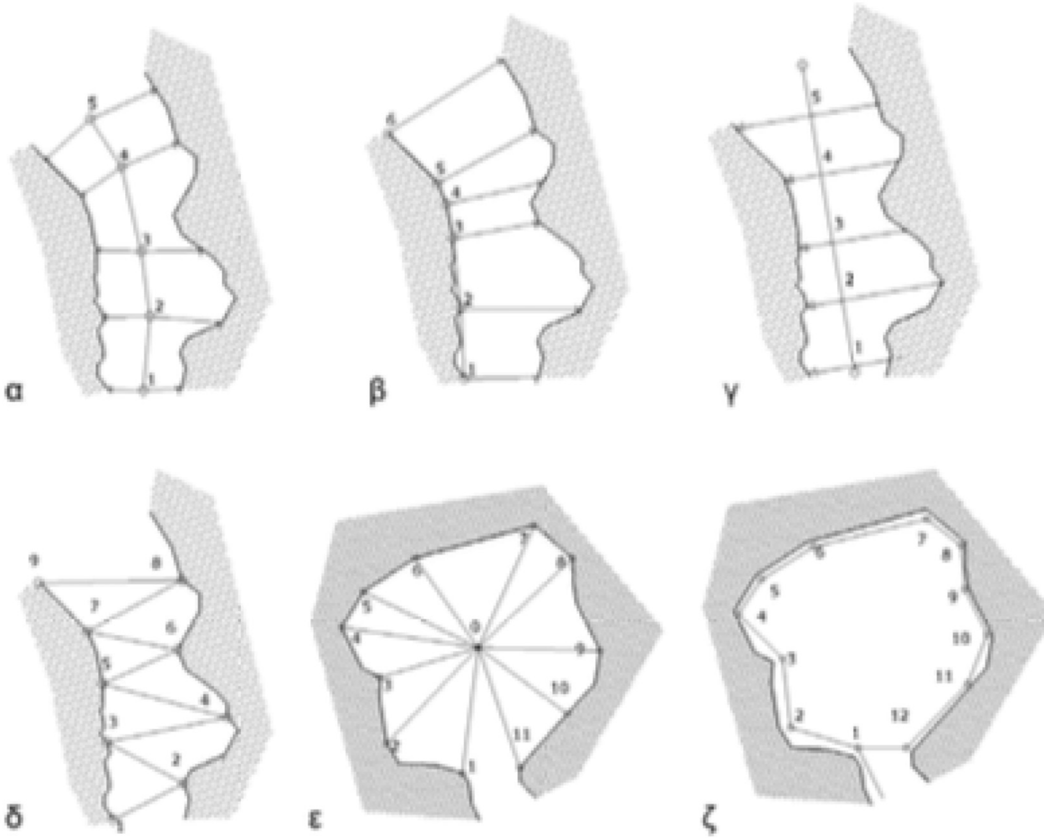

Fig. 1. The different types of routing for cave survey α, β, γ) central, δ) zigzag, ε) radial, ζ) circular.
(from Kalogeropoulos et al., 2008)

first stage. This group consists of 3–4 people in order to maximize the time available, especially in large caves, although a group of two people tends to cooperate better (Dasher, 2011). The leader of the group determines the location of the stations for the measurements, records the data in their diary by drawing sketches of the cave and usually designs the map, as it is easier for them to read the notes of the diary. The other members handle the instruments and report the indications to the leader (Savvaidis et al., 2007). Dealing with the instruments involves tape measurement of the distance from the station to the point in question, as well as the measurement of the clockwise angle that is formed between the station, the point and the magnetic north (azimuth). The station is the central point of the routing. Any routing can range from one to infinity, but a routing cannot exist without at least one station. The station can be set arbitrarily by the surveying group or be a set point in a general integrated geodetic reference system. The mapping procedure begins with the determination of a point-station (that either has specific coordinates according to a reference system or not). All of the other stations are determined in such a way that the shape of the cave is outlined. For every other station its distance from the previous one, the azimuth and the inclination are measured and recorded. Using this information, the stations can be drawn in a certain scale and can be orientated on paper. The procedure is repeated for as many stations as necessary. Nowadays, as will be showcased next, the mapping procedure has been simplified since 2008 as instruments that combine the capacities of a compass, a clinometer and a laser distance meter in an all-in-one device have been developed.

2. Mapping methodology

2.1. Routings

The measurements between the stations that take place for the collection of necessary data create a line in the cave that is called a routing. The routings can be open or closed. The beginning and the end of a closed routing coincide whereas in an open routing they do not (Kalogeropoulos et al., 2008). The former offers more accuracy in the mapping as it enables the cartographer to identify possible mistakes (Dasher, 2011). The routings that are applied in the cave mapping are categorized in four types: a) the central routing, b) the radial routing, c) the circular routing and d) the zigzag routing that are used depending on the shape and size of the space that needs to be recorded (Kalogeropoulos et al., 2008). In the central routing a central line is created in the middle of the space by the stations, from which the distance of the walls on both sides is measured (Dasher, 2011). The measurements on the sides are always made by measuring the azimuth. When the morphology of the cave allows it, the central line of the routing can be situated on one side of the passage in such a way that only the distance from the stations to one wall is measured (Dasher, 2011). In special cases the central line is straight and the distances of the walls on both sides are measured vertically from points of the line without requiring the azimuth (Savvaidis et al., 2007). In the case of a narrow passage the measurements can take place alternately from the one side of the passage to the other one forming a zigzag route. In this way each wall of the cave is defined better. Several cartographers believe that this routing alters the length of the cave, although this technique will offer more information to the final design (Dasher, 2011). In the radial routing the measurements occur from one station, in a central spot of the cave (or chamber), towards the borders of the space that is being mapped. The consecutive stations are radially positioned with regards to the central station. The radial routing is used in chambers where the space is almost circular and as such the central point is visible from all stations. In the circular routing the measurements take place circumferentially by following the borders of the space being mapped. In this case the shape of the routing coincides with the shape of the space that is being mapped. The circular routing is mainly used in chambers that are almost circular. This facilitates the 'closure' of the routing by making measurements from the last station to the first one. Consequently, during the design the possible errors become discernible (Dasher, 2011).

The question is whether there is one routing that outperforms the others when it comes to how accurately the space that is being mapped is attributed. In order to answer this question, in 2008, a group from the Aristotle University of Thessaloniki and the Local Department of Northern Greece of the Hellenic Speleological Society examined the accuracy of the routings by mapping an amphitheater of the School of Science and its antechamber using all four methods and then compared the outcomes against the actual architectural plans of the room (Kalogeropoulos et al., 2008). The same instruments were used for the measurements, including a SUUNTO compass and the electronic telemeter/clinometer of the department of Geology applied on a tripod. When they compared the results of the routings to the architectural designs of the chamber, it was proven that the radial routing was the most accurate while the zigzag routing was the least accurate (Kalogeropoulos et al., 2008 – see also Fig. 1).

Certain basic conclusions were drawn from this comparison of routings in 2008. Firstly, maps with different methodologies are not directly comparable between each other. Secondly the most accurate method for the mapping of the characteristics of the caves is radial routing because the points depend on a steady station. Finally, in radial routing the errors were minimized and if the moving of the routing radial centre between the stations is verified through triangulation and by repetitions of the measurements (back and forward, between the stations), the errors are minimized (for more information see also: Gazeas and Filippatou, 2008).

As far as caves with archaeological finds are concerned, in literature it is recommended to apply one single method of cave mapping, where the most accurate instruments possible should be used and the stations should be limited to the bare minimum (Tarsoly, 2006; Kalogeropoulos et al., 2008). What the above statements clarify is that accuracy in the mapping of caves and their characteristics are not only accomplished through the quality of the instruments but mainly via correct methodology and the experience of the mapping group.

2.2. Errors

It has been observed that the error rate in cave mapping is far greater than in attempts of mapping in any other field (Tarsoly, 2006). In a case where the purpose of the cave mapping is the examination of the spatial distribution and the spatial relations of its characteristics, the prediction as well as the correction of any errors is predominant (Tarsoly, 2006). Errors during the mapping can alter the results by diverging them from reality. The errors can be grouped together in the following categories: random errors, errors due to deviation from the alignment, errors due to deviation from the horizontal position, errors due to the incorrect recording of the readings (Savvaidis et al., 2007), systematic errors from deviation in the instruments due to their construction, errors due to the deviation from the prototype, errors due to the wrong strength being applied on the ends of the measuring tape during measurement and errors due to the deflection caused by the weight of the measuring tape (Kalogeropoulos et al., 2008). All of the above can be predicted in many cases if they are taken into consideration before the beginning of the mapping. In addition, as will be shown in the next section, the use of technologically advanced instruments can practically eliminate errors arising from the use of the analogue compass/clinometer and measuring tape.

The errors that are harder to forecast are the ones that are related to human error. They are unpredictable and the result of inexperience or exhaustion, hypothermia, darkness and the difficulty of adaptation in the area. Up to a point, the newest mapping instruments and the measurement analysis software limit human intervention. Nevertheless, even this software is still being developed and is not considered to be fully automated. Thus, it is still required to be handled manually. All of the above errors contribute to the fact that different mappings of the same cave produce results with slight or insignificant differences among them (Kalogeropoulos et al., 2008). These differences can be eliminated with the use of new technologies and software on the condition that the stations and the points that were used in the first mapping are used in the following mappings as well.

3. Heeb's paperless mapping

3.1. The instruments

In recent years, various distance meters have been introduced to the market however the majority of them do not provide an al-in-one solution with compass and clinometer. The development of an integrated electronic device to measure azimuth, inclination, and distance that can be used in a cave environment was needed. Needless to say there have been various attempts. Some never got beyond the prototype stage [EasyTopo] or were never good enough for cave surveying [Kombi]. The project DUSI by S. D'Espagner became a product, but was later retired. The SAP by Ph. Underwood, became product too, and it is now on stand-by. CaveSniper by J. Wojcicki, which is actively being maintained, is a niche product used only by a minority of cavers (for an overview see Corvi, 2017). DistoX, by B. Heeb, is the only device that got a worldwide distribution, and revolutionized the cave surveying practices. The reasons behind this success are (1) the design choice of an integrated instrument that measures distance, azimuth, and inclination in one shot, (2) a calibration procedure that can be carried out without special equipment, and (3) PocketTopo, a Windows PDA program to work with DistoX written by Heeb himself (Heeb, 2014). PocketTopo has become the de-facto program to use DistoX with a Windows PDA, and is probably the DistoX program most used in the field (Corvi, 2017). Heeb's "paperless system" is an integrated electronic cave-surveying tool. It consists of two parts: a) a combined Disto/compass/clinometer and b) a PDA based program to store and manage the measured data and to draw sketches directly on the screen (Fig. 2).

3.1.1. DistoX2 technical data

The current available DistoX2 consists of a modified Leica DistoX310 with a main part of the circuit is an ARM Cortex M0 microcontroller (STM32F051C8). It contains enough memory (8 k RAM, 64 k flash) to store every-thing including measured data and user options in the internal flash. An 8 MHz ceramic resonator is used to provide the clock precision necessary to drive the serial ports. The Bluetooth module used is a Panasonic PAN1321. Inclination is measured by the vertically mounted acceleration sensor present in the ×310. It is complemented by a second, horizontally mounted sensor (LIS3LV02) to provide full 3-axis measurements without making use of the less precise Z (vertical) directions. For the most critical X (forward) direction, the average of both sensors is used. (for an extensive presentation of the circuit see Heeb, 2014). The two devices are connected by a wireless Bluetooth connection (Heeb, 2014).

DistoX2 data according to Heeb are:

Range

Distance: 0.05 → 100 m (> 200 m under good conditions)
Azimuth: 0–360°
Inclination: −90°–+90° (no steepness limit)
Roll angle: −180°–+180° (fully tilt compensated)

Precision

Distance: 2 mm (0.05–10 m)
Angles: 0.5° RMS (after proper calibration)

Fig. 2. Leica DistoX2 and PDA with PocketTopo software.

Features

Selectable units: m/ft./inch, °/grad
Memory capacity: 1000 measurements
Laser Type: 635 nm, 1 mW, class II
Mechanical
Size: 55 × 31 × 122 mm
Weight: 150 g
Protection: IP65

Measurements are visible on the PDA screen within seconds. Results can be transferred to PC based cave surveying applications and graphics editors. These instruments have revolutionized cave mapping. They have reduced the members of the mapping group necessary, have increased the time of performance and have practically achieved accuracy in measurements, especially when operated on a tripod and aimed at a reflector. These instruments feature another comparative advantage. With the use of an industrial model for wireless personal computer networks (Bluetooth) they can send the data either to laptops or handhelds. These computers, equipped with suitable software, such as AURIGA and POCKET TOPO that will be presented in the following section, immediately analyze the measurements without human intervention. As Redovniković et al. (2014) proved, after a comparison between Heeb's paperless mapping and the traditional “tape and compass”, this leads to the direct limitation of human errors during the transcription of the measurements (see also Fig. 3).

3.2. Analysis software and their relation to GIS applications in caves

The two most renowned and widely used software applications – according to Corvi survey – (Corvi, 2017 Figs. 4 and 5) for cave mapping data analysis are Therion digital cave maps and Visual Topo. Therion is considered by many to be the most complete software of cave measurement analysis (see Wookey, 2004). Nevertheless, due to the fact that it is relatively difficult to use while at the same time its spatial database is limited, it has not found particular applications in archaeological cave research. On the contrary Visual Topo has been the most popular application among researchers because of its much more user-friendly interface, its simple and handy database and, at least to my experience, the fact that it offers immediate application of GIS elements in the mapping.

The software that was used in the present research was VISUAL TOPO. Before the completion of the reference to the mapping data editing software, it is worth briefly presenting AURIGA and POCKET TOPO that were mentioned in the previous paragraph. Both of these software systems were developed in order to cooperate with new mapping instruments (distance meters). These software packages aim to enable the user to directly transfer the data from the instrument to a handheld device (palm top) or a laptop (net book) either manually or wirelessly without necessitating the data being recorded on paper. This method, which is characteristically called paperless mapping, increases the mapping speed, minimizes errors and achieves greater accuracy in measurements (Fig. 6). The data from both AURIGA and POCKET TOPO can then be directly used in measurement analysis software like the ones that were previously mentioned (Le Blanc, 2004)

After the completion of the measurement analysis and the development of the stations and the points, what remains is the design phase. In simple cave mapping applications this part can be completed “manually” in the form of a sketch. In other cases, the final design can be done with any CAD or GIS type design software. PocketTopo offers an export in .dxf format (CAD format), which works relatively well but often has problems with georeferencing. The best way is to open the PocketTopo file in Therion and then export in .shp. Then the .shp can easily be exported in .dxf and used in CAD environment. In a case where it is necessary to mention particular characteristics of the cave on the map, such as decoration, hydrogeology information, constructions, or finds this can be done either with the immediate design of the information on the map or with the creation of a GIS file. In the case of the GIS the map is transformed in the GIS development program in either vector or raster form. Next, the characteristics are introduced based on their geo-reference, either in a local or universal coordinates system. The basic information that should be mentioned on the map is what should be mentioned in any other mapping, that is to say scale, legend, creator's name, North arrow, mapping group, mapping instruments, measurement analysis software and date.

As far as the legend is concerned, various symbolisms have been put forward for the interpretation of the cave characteristics – and of the present archaeology. The ones that are widely used are two; the mapping symbols of the National Speleological Society of the USA (N.S.S. U.S.A.) and the mapping symbols of the Universal Speleological

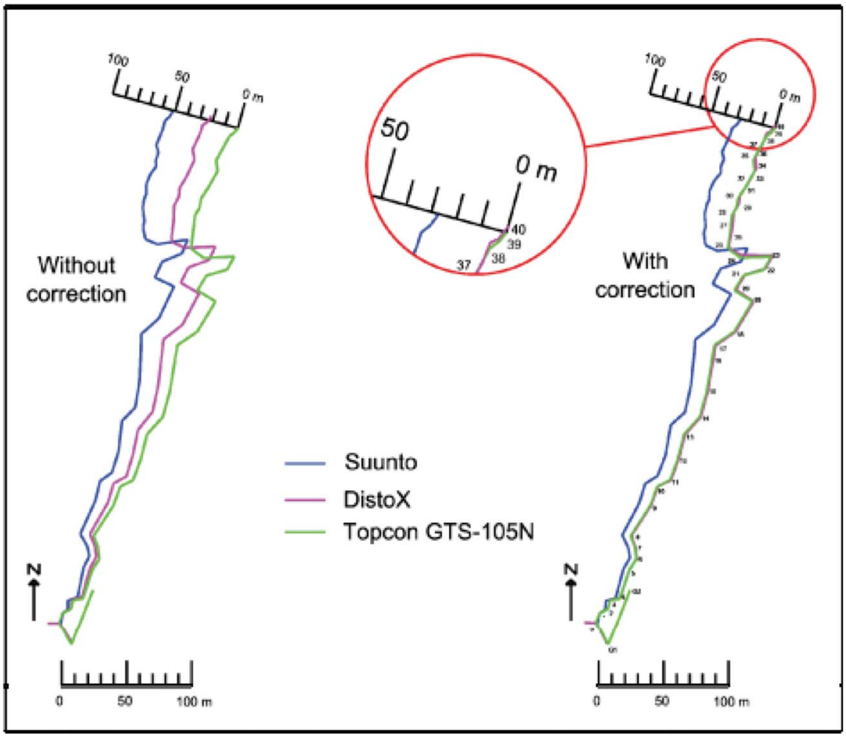

Fig. 3. Positional traverse deviation between Geodetic Station, Compass and Tape and DistoX survey.
(from Redovniković et al., 2014)

Federation (U.I.S.) (Dasher, 2011).

3.3. A note on the future of cave mapping software

Before the completion of the presentation of the techniques and the cave mapping instruments, it is worth presenting the new software and applications that are gradually becoming available and would seem set to dominate mapping in the future. While this paper was being written, the long-awaited version of PocketTopo for Android had not yet come out. However, three independent applications with the same characteristics and similar interface are available. These are Qave, Abris and TopoDroid. All these three applications are available for free on Google Play and have been completely developed by cavers not seeking to make a profit. There are though, no respective versions of these applications in Apple Store – or other application provider – available yet.

TopoDroid (sites.google.com/site/speleoapps/home/topodroid) was developed at the beginning of 2014 by an international group of speleologists. It is available in English, Spanish and French and is fully compatible with DistoX. Similar to PocketTopo the data is transmitted wirelessly and in real time from the rangefinder to the device. However, its complicated interface, as well as the fact that it needs various add-ons for additional functionality, have not made it particularly popular among researchers.

Abris (http://abris.shturmsoft.com/) started to be developed at the end of 2013. It is available in English and Russian and is not compatible with DistoX. As a result, the data must be inputted manually, which increases the possibility of errors. Nevertheless, among the three applications Abris has the most user-friendly interface and provides the greatest stability as an application. The sketches from Abris can be outputted as shapefiles (.shp) and the analysis of the measurements as a spreadsheet. Consequently, this is particularly useful when the final editing is to take place in a GIS environment. This is probably why this is the application with the most downloads according to Google Play.

It was more difficult to collect information on Qave as there is not an official webpage for the application. According to the page of the application on Google Play, it is compatible with DistoX. However, this does not seem to be the case as user comments mention that they have not managed to get a connection. Qave offers a reasonably user-friendly interface but does not have the design capability of Abris and TopoDroid.

The latest development in cave mapping and its finds seems to be the European Space Agency (ESA) tests for a portable Wi-Fi cloud and

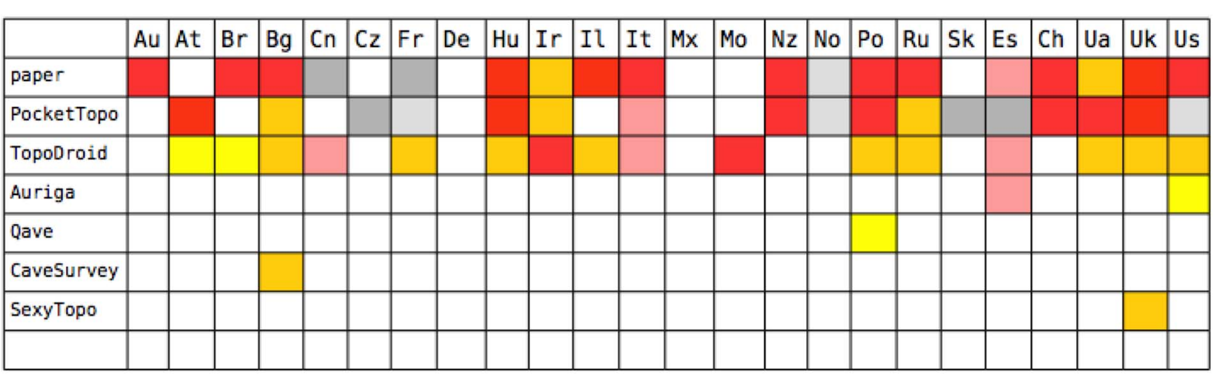

Fig. 4. Preferable application for cave survey data recording between countries – red the most used to grey least used; white no data; purple limited data (Corvi, 2017). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

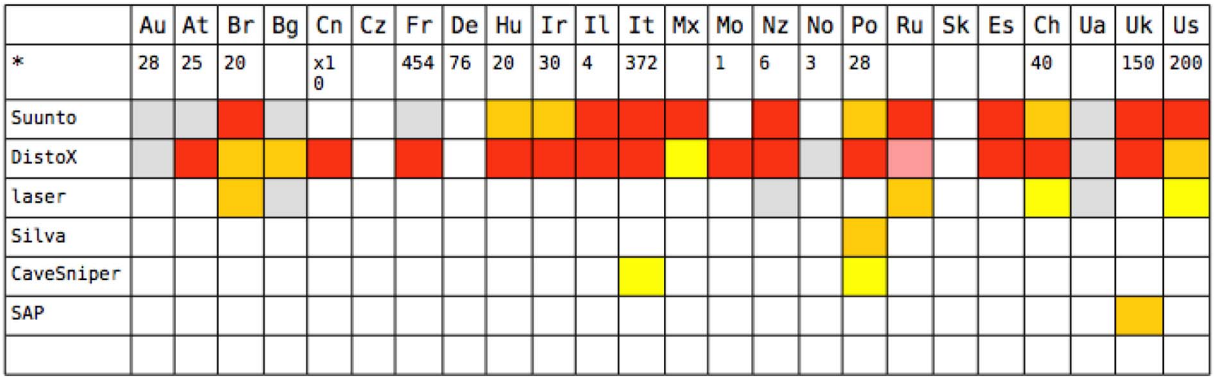

Fig. 5. Preferable instrument for cave survey between countries – red the most used to grey least used; white no data; purple limited data (Corvi, 2017). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

its application in the interior of the cave (see blogs.esa.int/caves/2015/02/03/wi-fi-and-tablets-go-caving-with-astronauts). To my understanding by creating a local Wi-Fi network the data from the mapping group can be transported directly to a central station, which will be equipped with an electronic computer and will not only perform real-time data processing but also real-time data analysis That is to say, the first data analysis will be done by the group while they are still in direct contact with the cave. As a result, errors will be detected immediately and whatever collection of additional data is required will be completed straight away. Human errors will thus be reduced to the minimum, as there will be no time gap between the data collection and its analysis.

Another recent innovation, which ought to be noted here, is the application of 3D photogrammetry in cave archaeological survey. 3D photogrammetry software, like Agisoft photoscan (www.agisoft.com), are based on an advanced algorithm which creates a 3D point cloud mesh of an object based on photographs that have been taken from different angles of the object. In order for the photoscan software to align the photos and to generate the point cloud mesh, photos must have a 60 percent overlay between them. Once the software has generated the 3D model, then a "texture" layer can be applied in order to re-create the feeling of the photograph. The real advantage of the 3D photogrammetry is the ability to georeference the 3D model based on just four ground control points. In a cave environment the ground control points can be located using either a geodetic station – where this can be used – or any of the other aforementioned cave specialized techniques. Once the 3D model is georeferenced then the user can extract geoTIFFs, photogrammetric plans, cross sections or simply measure distances under scale on the actual 3D model. Working with 3D photogrammetry in caves, creates a very difficult technical challenge of lighting properly and with consistency any area that recorded. Thus, even if the recording is properly conducted, the presentations of the 3D records are not of the highest quality. This is not a methodological problem though. Is a technical issue that maybe tackled in the near future using different lighting techniques and/or more advanced equipment.

Laser scanners, offers also good results for cave chamber mapping (see Funk, 2014 for a n application), but adequate when it comes to archaeology. The shadows that a laser scanner creates on cave floor usually compromise the accurate depiction of the archaeological features/finds. Additionally laser scanners share similar disadvantages to the Total Stations when it comes to operational costing and the size of the equipment that needs to be carried through narrow and wet passages.

4. Paperless mapping applications in archaeological fieldwork

In a comparative study Redovniković et al. (2014) tested a Total Station against DistoX and compass and tape (Suunto tandem with compass and clinometer) in Veternica cave in Croatia. Reading the outcomes of this study the "*good side of total station is the extremely high*

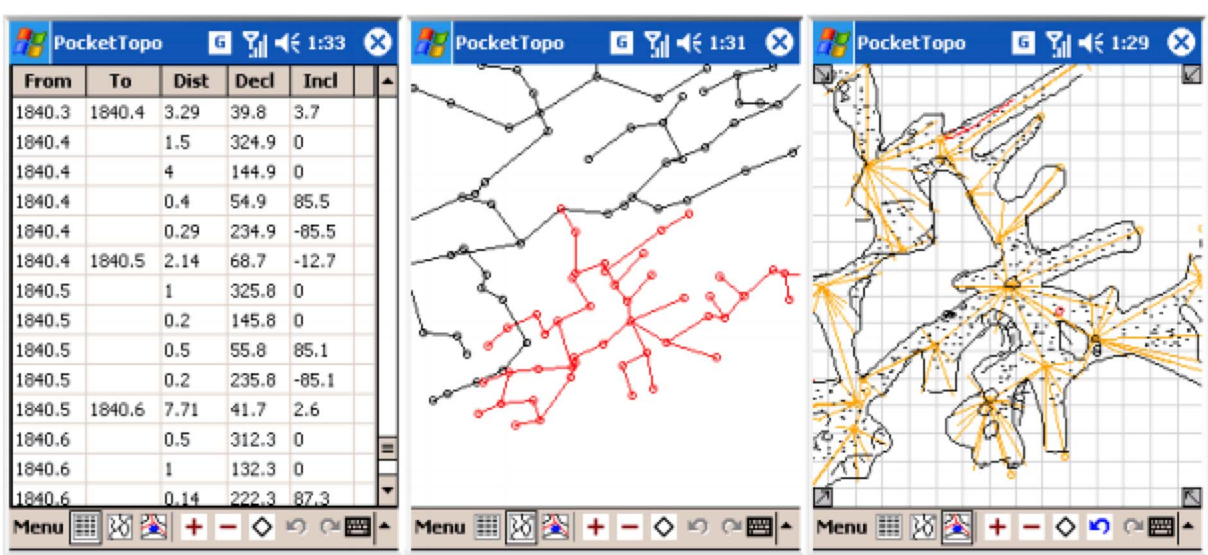

Fig. 6. PocketTopo interface screenshots: left, textual representation of branches and cross sections; middle, cave routings; right, cave branches auxiliary lines and real time sketching. (courtesy of B. Heeb – http://paperless.bheeb.ch/index.html)

accuracy, the automated transmission and the processing of data. On the other hand, the disadvantages are high cost, time-consuming process of surveying, bulking (weight and dimensions of the equipment), and this measurement method prevents the survey in extremely difficult areas". Using total station is possible regarding the conditions on the field (Redovniković et al., 2014:274). On the contrary "*benefits for DistoX are: moderate price, solid accuracy, small, lightweight, easy to handle, the overall measuring is faster because we only have one device to handle and it is not necessary to read and write results. Automatic data transfer also eliminates many sources of error. Disadvantage is that it also needs to take care of the fact that interfering objects have a detrimental effect on the determination of the azimuth*" (Redovniković et al., 2014:274).

To this day I am not aware for a wide use of Heeb's technique in cave archaeological projects. This may happens due to the luck of a general standardized methodology for archaeological cave survey – fieldwalk (for a discussion see Stratford, 2011 and Trimmis, 2013) or just because the archaeologists that using DistoX for their cave mapping have not publish on it.

In Kythera island speleological project (2010 – 2013), the author along with P. Filippatou, the project's cave survey officer, used Heeb's paperless mapping for the mapping of the island's cave and the recording of the surface pottery in the caves and the standing structures (see Trimmis, 2015). The simplicity of DistoX usage along with the user friendly PocketTopo allow several teams to work on different caves simultaneously with similar outcomes and accuracy even training time for the surveyors was limited. Also consistency has been achieved between caving methods since we did not have to swap between total station in rockshelters and easily accessible caves and DistoX in larger more complicated cave systems (Fig. 7) (for a detail presentation of Kythera survey see Trimmis, 2015).

In author's master research (2011 – 2012) DistoX and paperless mapping have been used for an archaeological cave survey in Kastoria prefecture n Northern Greece. Thirteen caves have been recorded surveyed and the positions of the surface pottery sherds have been recorded. Research in Kastoria was a project with low accuracy requirements as bioturbation factors can alter the precise location of the finds. Using paperless mapping, a small team of maximum four members managed in budget to explore, record and archaeologically survey 13 caves in a combined time of 17 days (for a detailed account on Kastoria survey see Trimmis, 2013).

For the surface finds recording, cavewalkers – as fieldwalkers in open-air survey – advanced of the surveyor and located the finds. For each find they placed a reflection peg. Each marked point measured from a mapping station with DistoX. The number of the point was copied in a finds register form together with the any comments and any image number. Afterwards in the VisualTopo environment finds' locations and types were recorded in the window "Comments" of this particular survey point along with a brief summary of the characteristics of the finds. Then if there was a photo for the find, this was added in the relevant field.

This feature is probably the only real advantage – possibly along with the user-friendly interface – that VisualTopo offers in comparison with Therion. Because with VisualTopo you are not just get an X,Y,Z location of a point but also a built in database that can store information and images that refers to this particular point. Then all these can be exported either directly to illustration software – as it was the case in Kastoria (see Fig. 8).

Kastoria's fieldwork showcased the importance of a mobile device

Fig. 7. P. Filippatou mapping in Charambos tou Giorgi pothole, with DistoX1 and PDA during the Kythera Speleological Project.
(courtesy of the author)

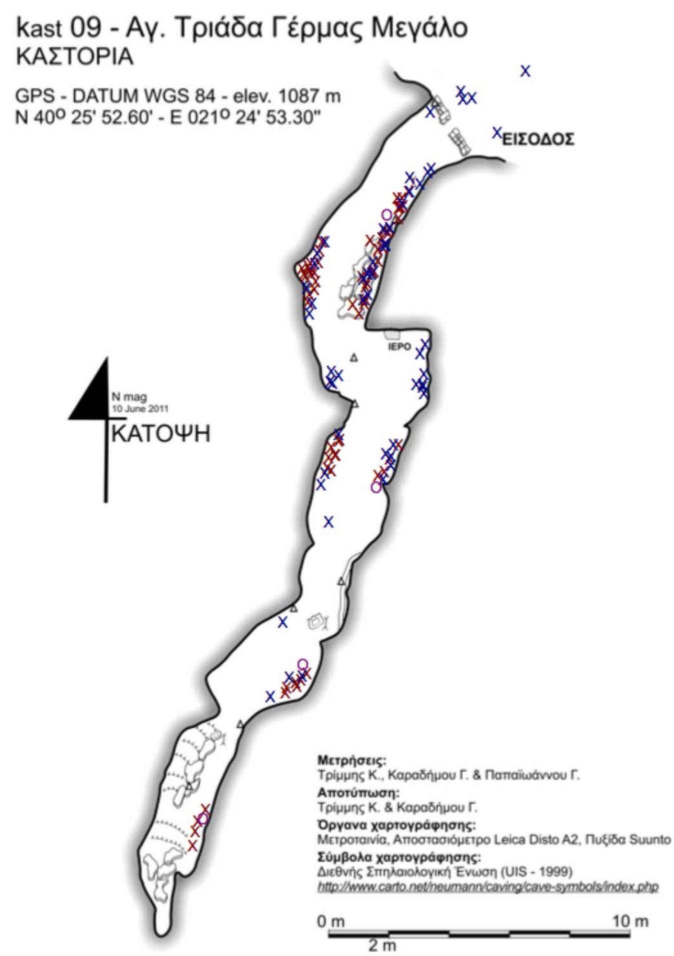

Fig. 8. Agia Triada cave with annotated pottery sherds location (blue X wheelthrone pottery- red X handmade pottery). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
From Kastoria Cave Survey

Fig. 9. Image from Katafygadi chamber B. Reflective markers annotate Late Bronze Age pottery concentrations. DistoX1 is on the right hand side of the picture.
(courtesy of P. Filippatou)

for archaeological survey in caves. In open air sites DGPS or handheld GPS devices have solve this problem. Heeb's paperless mapping methodology and DistoX can be this standardized device so field walking in can have a high accurate, low cost, easy to use system. It is worth to mention here that DistoX field accuracy is far greater that hand held GPS error and equal to most of DGPS platforms (see Redovniković et al., 2014 on DistoX accuracy tests).

The author in collaboration with K. Trantalidou and the surveyor F. Stefanou, has also used in Katafygadi excavation in Kythera island. The main reason for selecting DistoX as the main survey instrument was the very narrow passages that the cave has. Once you cross the passages then small low ceiling chambers with archaeology appears (Figs. 9 and 10). Even if we cannot compare DistoX outcome with any other instrument in this project, the device handle the excavation Data fiercely and support the data spatial analysis research equally good with data from caves that Geodetic Stations have been used – according to F. Stefanou previous experience.

5. Conclusion

In order to summarize the detailed presentation of Heeb's technique for archaeological cave mapping I am going to present a step by step guide of how to use paperless mapping on a project from the instruments selection to data presentation. Depending on the complexity of

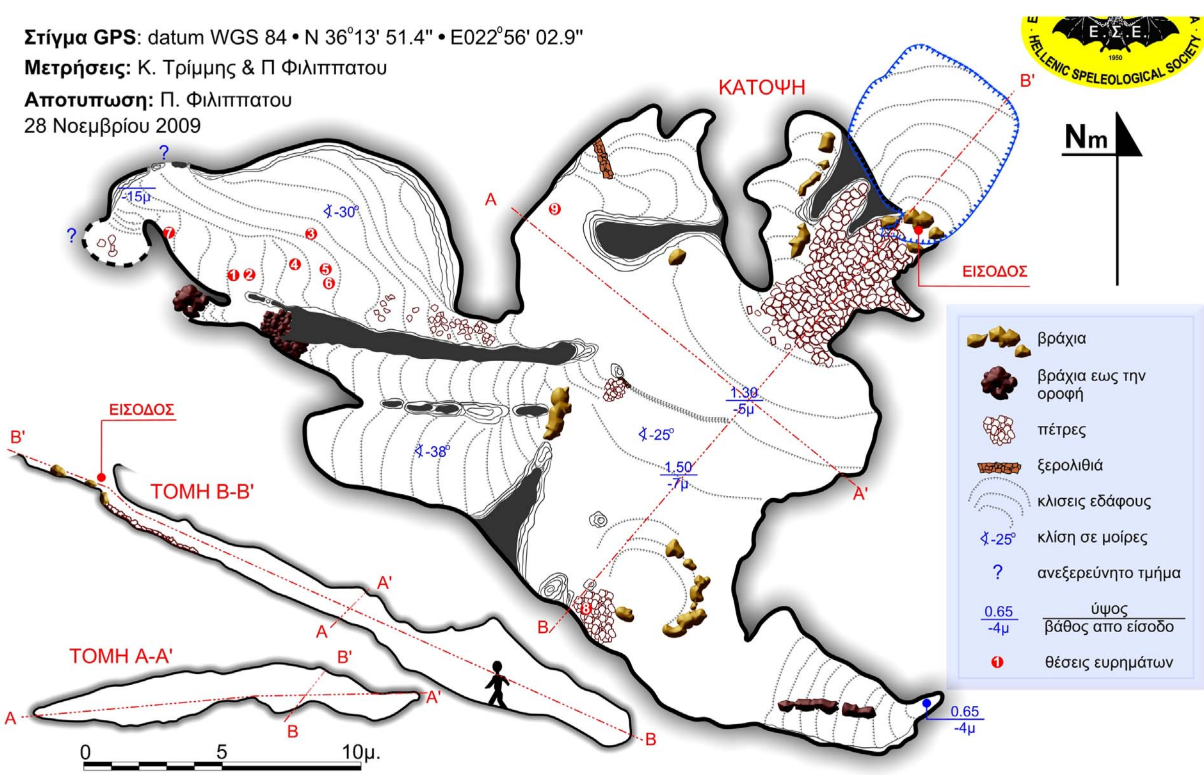

Fig. 10. Map of Katafygadi cave in Kythera. The Late Bronze Age pottery concentrations are marked with red dots. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the cave, the first step is to select the best measuring instrument. Geodetic stations are the best option for less complex caves without saturated environments and "letterbox" passages if the budget and the personnel can handle such an instrument. For more complex caves or for projects that do not required absolute accuracy the best solution on the market at the moment is DistoX2.

a) Mapping methodology
Before the application of any state of the art instrument or technique the surveyor needs to select the best routing methodology for a complex cave mapping. As has been tested by Kalogeropoulos et al. (2008) radial routing with limited stations and cross measuring between the stations is by far the most accurate method. A precise methodology on the routing selection can increase the accuracy of any cave survey even of these that have been conducted using a compass and a tape.
b) Data collection and management software
Data from DistoX2 will be transferred via Bluetooth to a PDA with Pocket Topo. Alternatively, mobile Android (for the moment) applications like Abris or Quave can replace a PDA and the Pocket Topo, for data collection and management. One of the strong advantages, both for the Pocket Topo and the Android application is the ability that they offer to the user to sketch a map on the app in real time as they are mapping the cave. In such a complex environment this tool eliminates the use of paper blocks (that can be wet or muddy), accelerates speed and limits user errors.
c) Data analysis software
For the analysis of the data from the cave and the initial map drawing, any CAD or GIS software can be used. The dominant software for cave data analysis and mapping at the moment is Therion, command-line interface software that combines measurement analysis abilities with an advanced map generator interface. Therion is compatible with GIS software (see Corvi, 2015) but does not have a built-in database per point tool, which is very helpful for both archaeological and microenvironmental mapping. This tool offers the user the ability to add specific qualitative and quantitative information for every point in the survey. Visual Topo, the software that I have been previously described in this paper, offers this tool, but the limitation of a sustainable illustration plug-in have made the software dated.
d) Spatial analysis software - Photogrammetric solutions.
Any GIS software is still the best solution for the spatial analysis of the data and the correlation between the micro-climatic – sensorial – data and the archaeological evidence. The application of GIS in cave archaeology has its own disadvantages (such as the lack of a truly three-dimensional correlation between the data – see Moyes, 2002 for an application and Trimmis, 2013 for a review). Even though the future is promising for 3D based photogrammetry and spatial analysis, GIS remains the main tool for spatial analysis due to the convenience that the interface offers and the almost unlimited spatial analysis toolbox that is available for the user.
e) Map and data presentation
The final step is the visual presentation of the data on a map. In the case of a research without the analysis part, Therion offers a cave map-designing interface where the archaeological data can be projected without the implementation of any other advance software. In a case where another analysis software has been used, any illustrator or CAD software can be used for polishing the map and presenting the data.

From my experience so far, from applying Heeb's paperless mapping in archaeological surveys, in the strengths of the approach can be included the mapping speed and accuracy, the low cost, the minimization of human made errors, the ability to handle qualitative data, the ability to support geo-spatial models based on qualitative data and the way that archaeological evidence can be discussed in correspondence with the micro-climatic data. DistoX may cannot replace a Geodetic Station in a high accuracy demanding cave excavation – if an instrument such this is not restricted by cave's environmental factors; Surely though Paperless Mapping it is the technique that should be used in subterranean research as the closest equivalent to DGPS/handheld GPS for the open air sites.

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