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Geographic Information Systems in Archaeology: A Systematic Review

RESEARCH ARTICLE

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ABSTRACT

GIS are an essential element in archaeology. Their use has become widespread for their potential to store, reference, analyse and visualise spatial information. Nonetheless, to the best of our knowledge, a systematic review of academic peer-reviewed publications related to the use of GIS, as a framework, in archaeology has never been presented before. Our goal in this work is to identify what has been published so far in relation to using GIS in archaeology within a small selected sample. We used the PRISMA guideline to perform a systematic review of 671 publications that we identified using the SCOPUS database and the keywords 'GIS' and 'archaeology'. The collected publications were screened, analysed, and categorized into different relevant categories. Our analysis shows that GIS, in our selected sample, are mostly used for visualization and information management tasks. Moreover, spatial analysis studies were more common than other studies, and theoretical publications are scarce. The lack of a theoretical background in GIS may be the cause of some of the problems related to GIS applications in archaeology.

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1. INTRODUCTION

Geographic Information Systems (henceforth GIS) have been widely used in archaeology since the 1980s and they are an essential element of any archaeological study that works with spatial data (Llobera, 2006: 111). GIS are valued for their information management capabilities and their potential for spatial analysis (Gillings et al., 2020a: 11). Their use has become widespread thanks to the availability of data, the development of several software applications (which have become more user-friendly and have increased its different functionalities), and the possibility of using open-source resources (Connolly & Lake, 2006: 1). Consequently, there is a large corpus of related publications in which GIS is used with archaeological purposes.

To the best of our knowledge, a systematic review of peer-reviewed publications on the topic has never been done before. A systematic review can be defined as '*a review that uses explicit, systematic methods to collate and synthesize findings of studies that address a clearly formulated question*' (Page et al., 2021b). Systematic reviews serve many roles. They serve as syntheses of the state of start within a field, they can identify issues and problems in previous studies and answer questions which would not be able to be answered by individual studies and, finally, they can also serve to create or evaluate theories about why certain phenomena occur in that area of research (Page et al., 2021a).

GIS, despite their potential, also have drawbacks. Firstly, to be able to use them, one must have education in these technologies. Moreover, using GIS without fully understanding the nature of these tools and the procedures can also give the false sense of security that the results obtained are infallible (Brouwer Burg, 2017), which is not necessarily the case. A correct application of GIS requires having knowledge in different disciplines, such as geography, mathematics, or computer engineering for its most technical part. It also requires an adequate spatial thinking framework for its analytical and interpretative areas. All these elements make using GIS in archaeology challenging and they may prove an issue when trying to use these tools and procedures with archaeological purposes.

In this article, we aim to do a systematic review that addresses the state of the art within the academic world of GIS applications in archaeology. To do so, we have followed the PRISMA statement for systematic reviews (Page et al., 2021a, 2021b) that provides a framework for systematic review studies. Our goals are the following:

- **Identify the research trends** in GIS applications in archaeology in relation to methodology and type of studies.
- **Pin down where the publications are coming from and the possible implications**. We will identify where are the research centres where the authors are based.
- **Identify potential problems**. For example, Conolly and Lake (2006) pointed out that many archaeologists, twenty years ago, only used GIS to store information because they did not know how to perform more complex functions of GIS like spatial analysis or support other archaeological objectives.
- **Identify what kind of publications have a higher impact and why**.
- **Identify what is the background of the researchers who write these kinds of studies**. We will identify the education of the researchers.

We also seek to explore some questions related to the data we gathered. We want to see what are the techniques that have been most used and what type of studies have been more common and potentially propose explanations.

2. METHODOLOGY

The review was undertaken between May 2022 and September 2022 following the PRISMA review guideline. PRISMA was designed to help systematic reviewers transparently report why a review was done, what the authors did, and what they found (Page et al., 2021a, 2021b). It also states how this review must be conducted.

2.1. SELECTION CRITERIA

The *SCOPUS* database (www.scopus.com) was used for searching the keywords 'GIS' and 'archaeology.' The software *Mendeley* (www.mendeley.com) was used to manage all the references. The selection process of peer-reviewed publications first involved an analysis of the titles and summaries. Subsequently, the last screening involved a study of the contents of the selected publications for the final review. The first search returned 671 publications spanning from 1990 to 2022, 10 of which were duplicate records that we removed before the screening. The first screening excluded 18 publications. These publications could not be accessed due to not being available digitally or in open-access. The reports of the 643 remaining publications were assessed for eligibility by reading their summaries and titles. Of these, 72 were excluded. The criteria we followed to include or exclude a paper was the following:

- **To be included, a publication must have a relevant GIS application for any archaeological purpose**. By 'relevant' we mean that a GIS procedure or approach was used for a specific purpose related to archaeology, such as answering a historical question or managing archaeological data. This requirement was not meant to be very exclusive as the intention

was to analyse the use of GIS in archaeology as a framework.

The reasons for exclusion were the following:

- GIS or their use are not the focus of the article (e.g., Moyes & Montgomery, 2019). Some studies involved the use of GIS, but it was not central or relevant for the authors' goals. Certain studies involved a partial use of GIS, but the objective of these studies could have been achieved without its use. In some cases, the use of GIS was residual.
- GIS was not employed for the study (e.g., Pryce & Abrams, 2010).
- The GIS methodology is unclear (e.g., Buckles et al., 2002). In certain cases, it was hard to understand what the authors had done in relation to GIS as they did not explain their methodology in an adequate way.
- Archaeology was not the focus of the publication (e.g., Safia & Aicha, 2014).
- The publication did not have sufficient information for our analysis (e.g., Ruiz-Gálvez et al., 2014). Certain papers did not include all the information we required for the categories we used to extract information (explained in the next section).

Consequently, this review assessed 571 publications. The records and the studies were reviewed by one author. A flow diagram that describes the sources, numbers, and fates of all identified and screened records in our review is depicted in Figure 1.

2.2. EXTRACTION OF INFORMATION FROM STUDIES

The 571 selected publications were classified into distinct categories. Data was collected in relation to the year of publication, researchers' background, location of the

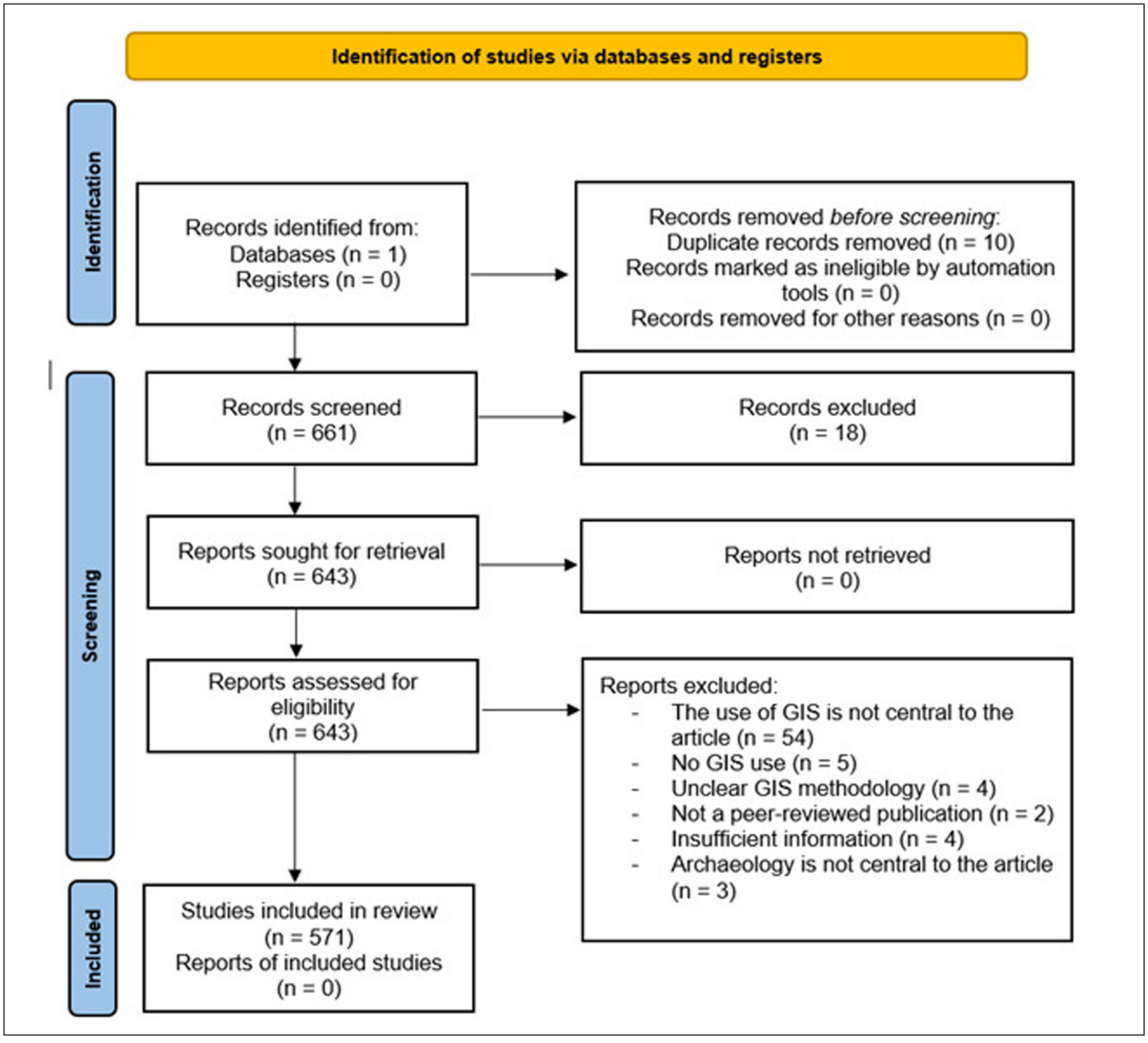


Figure 1 PRISMA flowchart of the review. Our sample only included peer-reviewed publications.

research centres, location of the studies, type of study, GIS techniques employed, citations and language.

The year of publication was determined by the information in the paper. We gathered this information to see if patterns were specific for a time scope and potential shifts in research.

The researchers' background was determined by the information in the publication or from their academic profiles in ORCID. If neither was available, other sources (university websites, Academia.edu, ResearchGate, etc.) were sought to obtain the information. North American anthropologists were classified as 'archaeologists' in the study taking into account that archaeology is considered a part of anthropology in the USA and Canada (Bahn, 2012: 14; Gillespie et al., 2003). If the publication was co-authored and there were different backgrounds for each researcher, the study was considered 'multidisciplinary'.

The location of the research centres was determined from the information provided in the publication. If the paper was co-authored by researchers from different institutions that were not in the same country it was considered as an "international collaboration". Location of studies, on the other hand, refers to the place in which these studies were focused. For instance, a publication focused on an area of the Apennines would have 'Italy' as location of study. If the area of study comprised many different countries the information was gathered (see appendix 1) but was not used for the study.

'Type of study' refers to what end GIS was used for and is based on the main applications described by Connolly and Lake (2006). We named them 'heritage management', 'spatial analysis' and 'fieldwork techniques'. To these three types we added 'GIS and Archaeology relationship' for those papers focused on the interrelation of GIS and archaeology and their theoretical implications; 'public archaeology', for those papers whose main goal was to make archaeological knowledge available outside academia; and 'teaching', for those papers focused on the education of archaeologists in these technologies. It must also be mentioned that some papers could be classified as more than one type. In these cases, the decision to classify a publication as one type or another was determined by the goal of the paper. For example, if a study aimed to locate archaeological sites to protect them and did so by using spatial analysis it was classified as 'heritage management'. If another study applied the same spatial analysis but its aim was to answer landscape archaeology questions, it was considered a 'spatial analysis' study.

'GIS techniques' refers to which methods were used or how was GIS employed. We must mention that the techniques utilized were truly diverse and a category was created for each technique used in the publications. It must be said that two of these categories ('mapping' and 'information management') are present in most of the articles. In many studies mapping (e.g., Warner-Smith, 2020) and or information management (e.g., Petrosyan et al., 2021) were the sole technique employed, or their use was particularly important for what the authors intended in their study. In such cases, these categories were attributed to the publications. If mapping was not the main goal of the article it was not classified as mapping in this category even though most of the publications had map visualizations. Some publications involved more than one technique so when we did the statistical analysis, we considered all the techniques. Consequently, our sample for this category is bigger than the number of articles.

The number of citations was obtained from Google Scholar (scholar.google.com) as the citation information from SCOPUS is limited to their database and was too restrictive. The language of the publication was also referenced. We had no difficulty in reading publications in English, Portuguese, or Spanish. If the publication was written in another language the English summary was used. If it did not have the necessary information, translation engines were used. As the keywords we used for the review were in English, the review did not gather many publications written in other languages. Over 92% of the publications were written in English. The remaining 8% involved publications written in Croatian, Czech, Dutch, French, German, Italian, Polish, Portuguese, Russian, Simplified Chinese and Spanish.

Having gathered all this information for every publication individually, the information was analysed statistically as a whole and presented with bar charts, maps, and tables. It is also necessary to say that the sample we collected is small and does not include all the publications in which GIS is applied to archaeology. Those papers in which 'GIS' is not included as a keyword will not appear in our sample, for instance.

All the publications that were analysed and the different categories associated to each of the papers can be consulted in appendix 1.

3. RESULTS

The researchers' background results are shown in Figure 2. 45.71% of the publications reviewed were written by archaeologists and 36.78% of the papers are attributed to multidisciplinary teams. These multidisciplinary teams always involved an archaeologist as a co-author. Geography (with 6.30% of the data) was the second most common background for the authors. The remaining 12% of the papers were written by researchers of very different backgrounds such as geology, environmental sciences, or computer engineering.

Regarding the origin of the publications (the research centres where the authors were based), 108 publications came from international collaborations (18.91%). In Figure 3 we show a map with the location

of the research centres of the papers that did not involve international collaborations (463 publications). North America and Western Europe are the main hotspots for the institutions that have written papers in which GIS is applied to archaeology. 21% of the publications came from institutions in the USA, 10,6% have an origin in British institutions and then we have Italian, Spanish and German which account for 9.09%, 7.36% and 5.19% respectively.

In Asia, most publications come from Chinese and Indian research centres; in Oceania, Australia is the main country where the research centres are located; in South America, Argentina is the country with more papers associated to their institutions. Africa is the continent with fewest publications coming from their research centres though there are South African, Egyptian, and Moroccan institutions generating contributions.

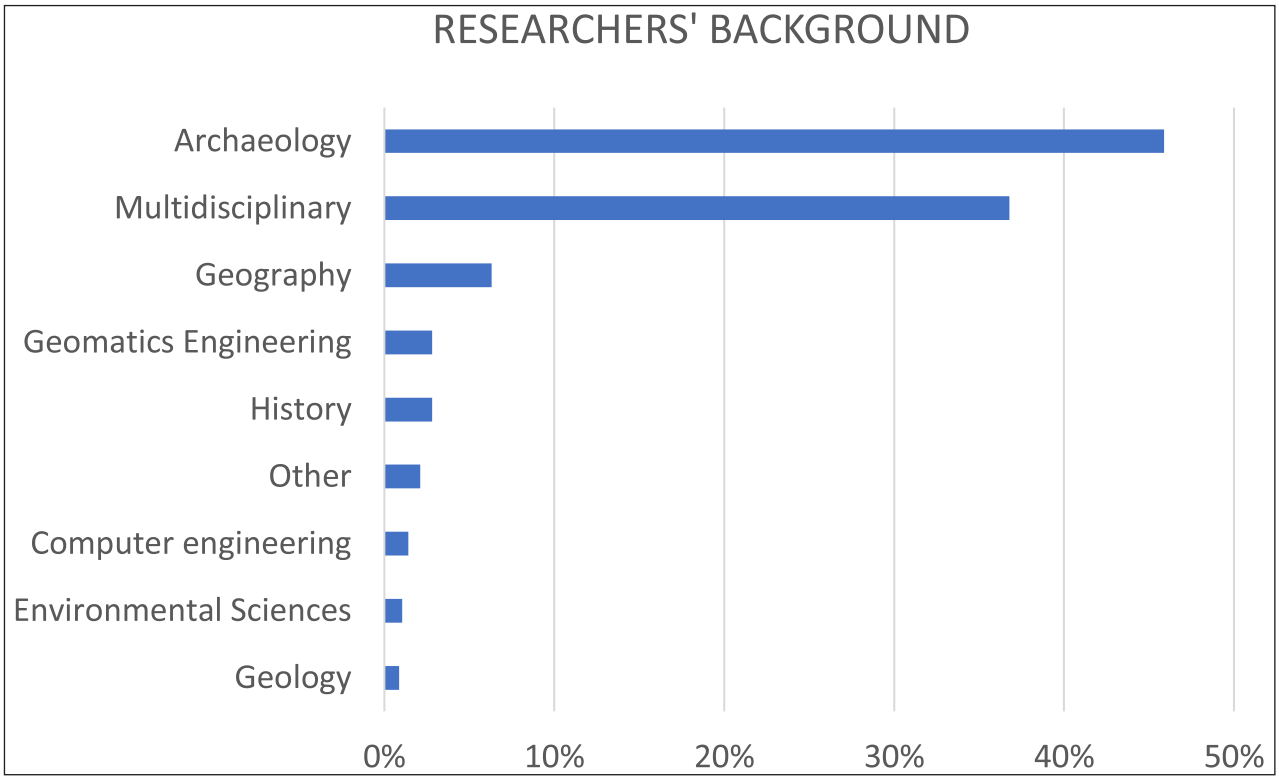


Figure 2 Researchers' background of the authors that wrote the papers selected for our review.

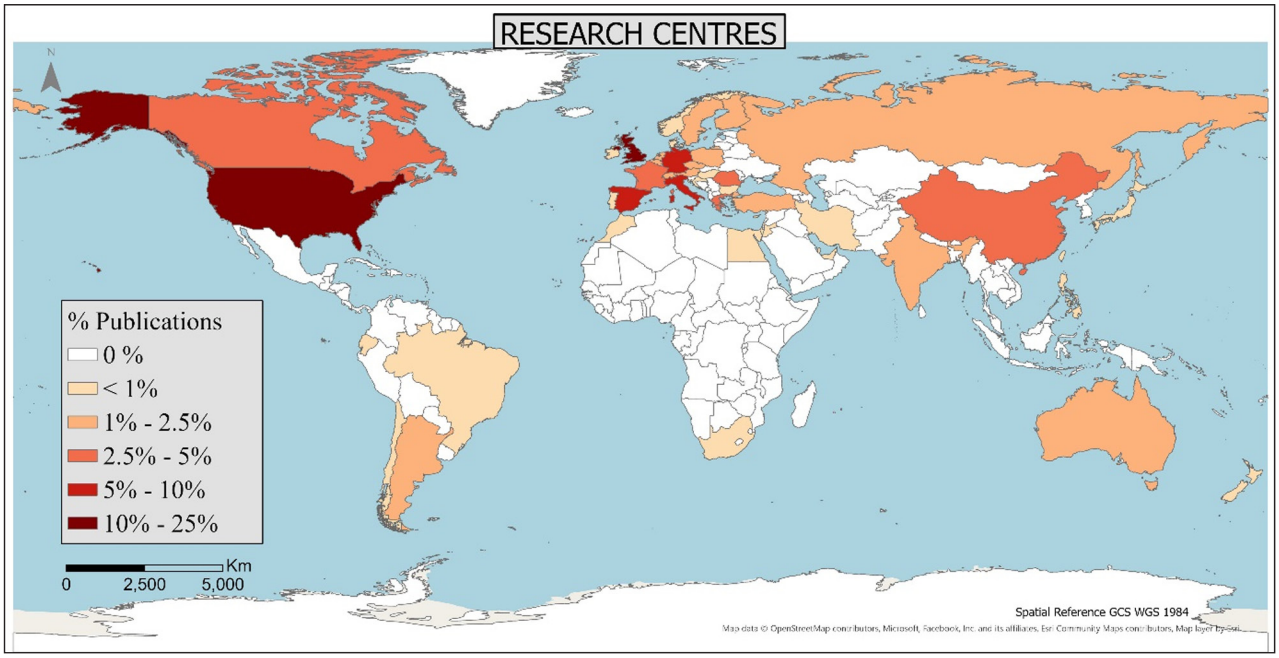


Figure 3 Map showing the percentage of publications associated to institutions in each country (excluding international collaborations).

In Figure 4, we can see in which countries these studies were conducted (studies which focused on broad territories that comprised many countries were not included for the elaboration of this figure). The distribution tends to be similar to the location of the research centres. Nonetheless, there are some slight differences. There is a higher percentage of publications applied to territories in the Near East, Central America, and South America. In these cases, most of the academic knowledge that is being produced is coming from foreign institutions.

Moving on to the type of studies (Figure 5), 49.04% of the reviewed papers were spatial analyses publications and 33.45% were heritage management publications. In 7.71% of the papers GIS is applied to fieldwork techniques and 7.18% account to theoretical papers about the relationship between GIS and archaeology. We finally have 2.25% of public archaeology publications and 0.35% dedicated to teaching GIS to archaeologists.

We also identified two temporal trends. From 1990 up to 2010 most publications were heritage management publications (Table 1) yet in the last 12 years, the amount of spatial analyses studies has increased. At the same time, the proportion of theoretical papers (GIS and

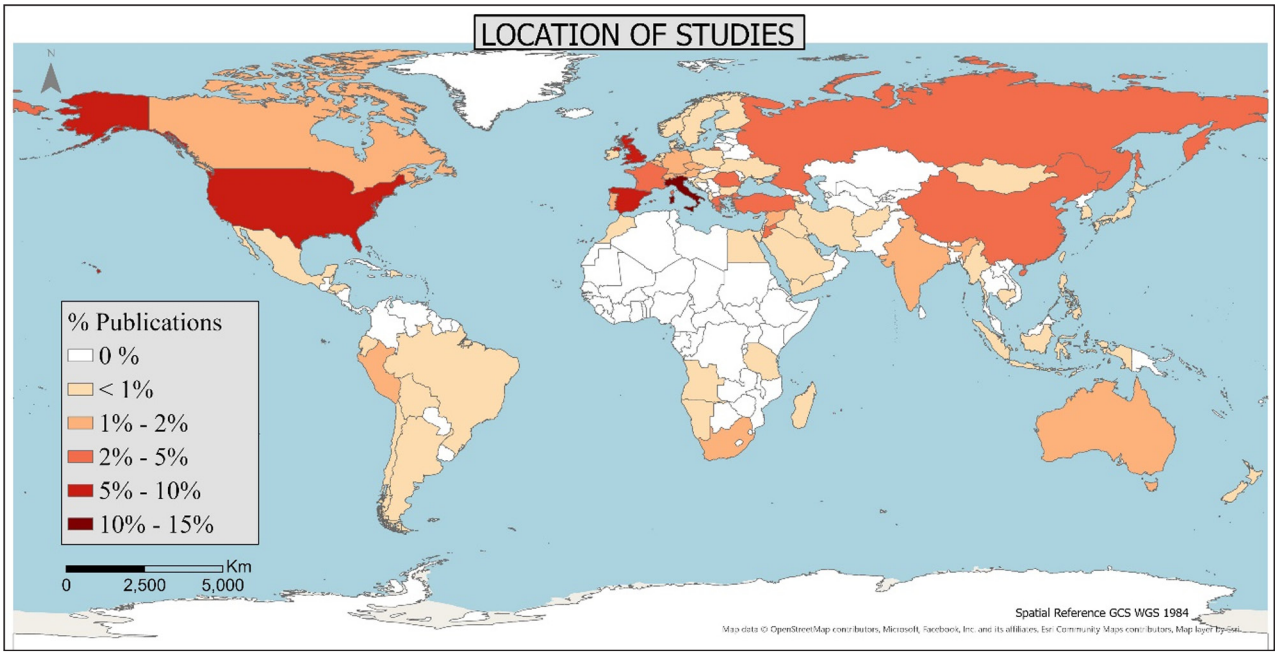


Figure 4 Map showing the area of study (at country level and in percentages) of the publications.

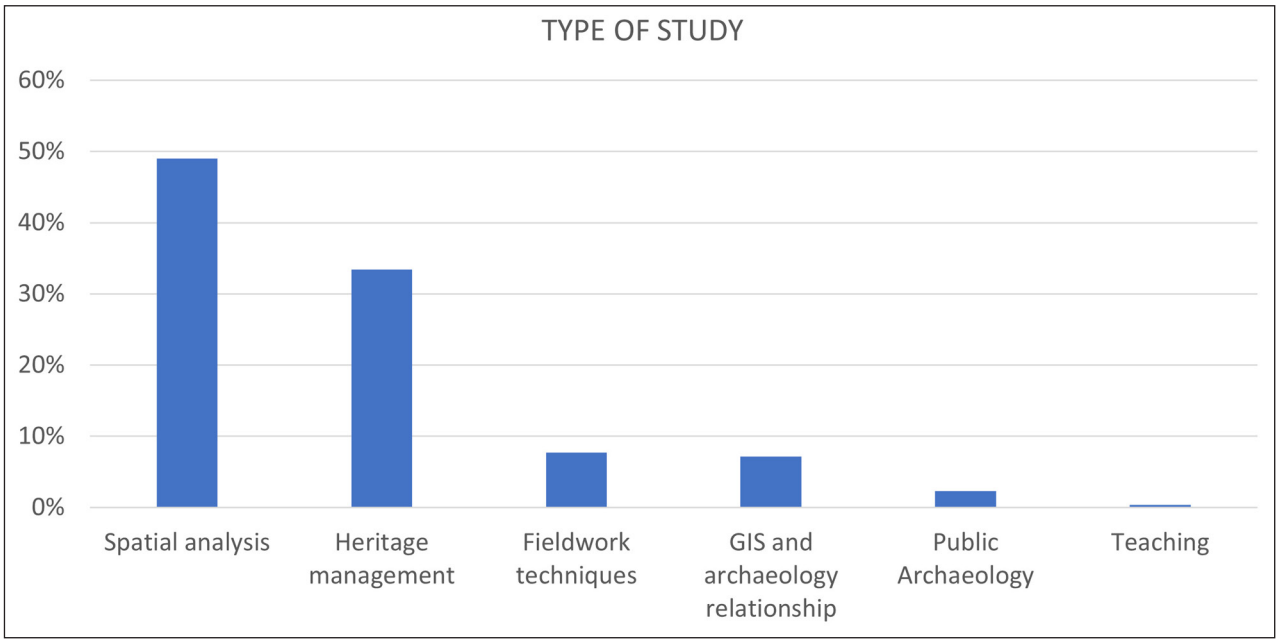


Figure 5 Type of Study statistics.

archaeology relationship) has decreased in the last 12 years. These findings are described in Tables 1 and 2.

Speaking of the GIS techniques (Figure 6), we can see that GIS was used in many ways. Among these, mapping (19.40%) and information management (16.40%) were the main tasks. Within the analytical area, predictive modelling, multi-criteria approaches, visibility studies, density analysis and spatial statistics are the most common techniques employed by researchers. There is also a relevant number of publications related to the

TYPE OF STUDY	% TYPE OF STUDY(1990–2009)
Heritage management	44,25%
Spatial analysis	32,74%
GIS and archaeology relationship	13,27%
Fieldwork techniques	7,08%
Public Archaeology	2,65%

Table 1 Table showing 'type of study' proportion of publications (in percentages) from 1990 to 2009.

TYPE OF STUDY	% TYPE OF STUDY(2010–2022)
Spatial analysis	53,06%
Heritage management	30,79%
Fieldwork techniques	7,86%
GIS and archaeology relationship	5,68%
Public Archaeology	2,18%
Teaching	0,44%

Table 2 Table showing 'type of study' proportion of publications (in percentages) from 2010 to 2022.

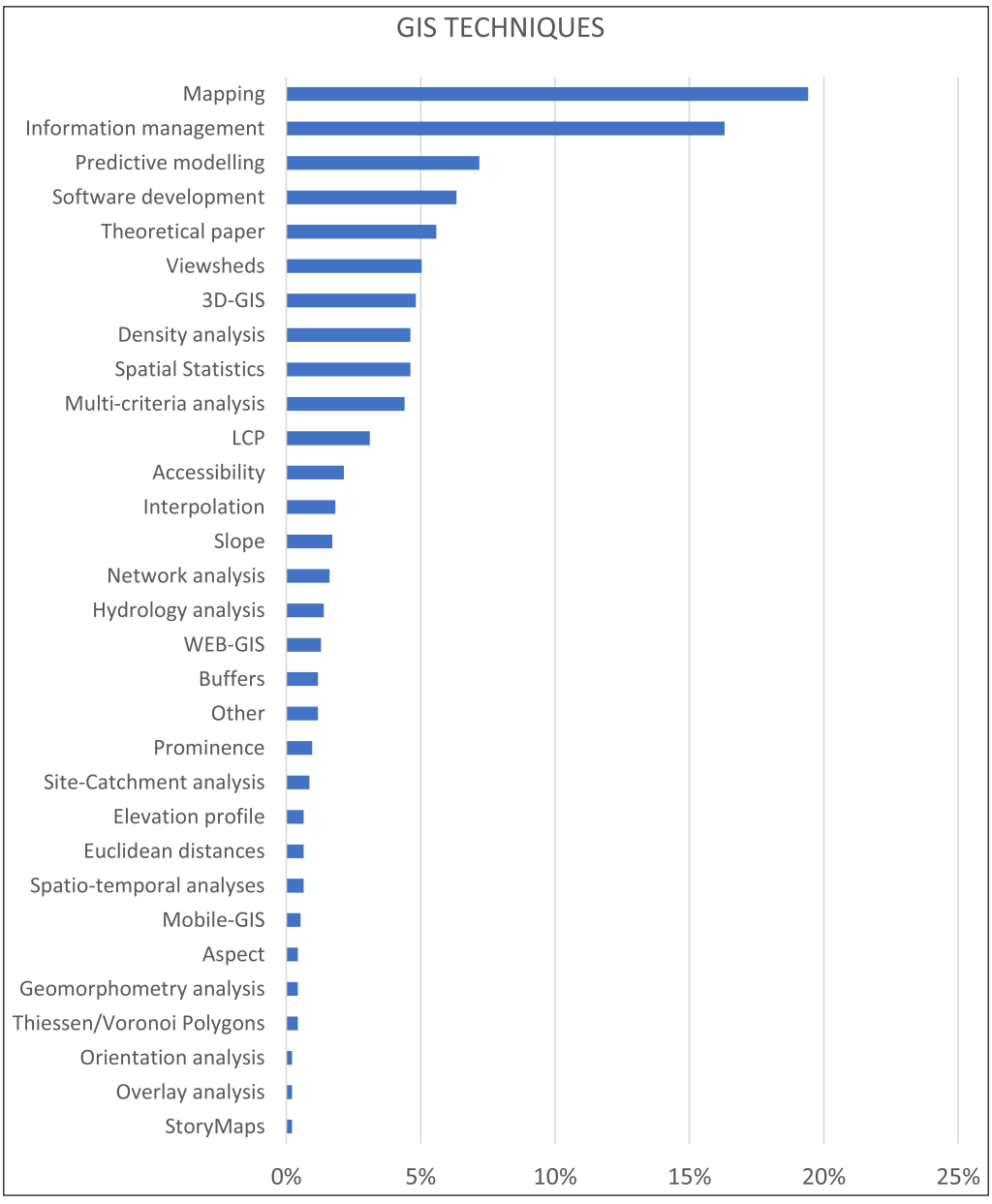


Figure 6 Statistics for the different GIS techniques or procedures employed in the publications we analysed.

TYPE OF STUDY	AVERAGE CITATIONS PER YEAR
GIS and archaeology relationship	4.90
Spatial analysis	2.55
Heritage management	1.87
Public Archaeology	1.65
Spatial analysis	1.48
Teaching	0.00
Overall average	2.38

Table 3 Table showing the average citations per year for each type of study.

development of GIS software or tools. These papers deal especially with developing WEB-GIS applications, GIS tools or other software specifically designed for archaeological purposes.

Regarding the average citations per year of the publications (Table 3), 'GIS and Archaeology' theoretical papers have the highest average citations per year (4.9 citations per year), followed by spatial analysis studies (2.55 citations per year). The rest of papers had a lower number of citations per year than the overall average.

4. DISCUSSION

The analysis of the papers we reviewed show that most of the publications were written by archaeologists. Is this positive or negative? We consider the fact of archaeologists becoming increasingly involved in GIS to be positive. GIS potential in archaeology is widely recognized and archaeologists are engaging more and more with digital technologies. The results of our analysed sample show that there is a growing interest in the use of GIS.

The question we must ask ourselves is if archaeologists have enough knowledge or education to correctly apply these technologies. In 2011, the INRAP, the French research institution for preventive archaeology, started a GIS education programme for its employees (Badey & Moreau, 2018; Rodier et al., 2010). The institution acknowledged the importance of GIS but also found that most of their archaeologists were not digital-native users and tried to revert the situation. We cannot conclude how common this situation is among archaeologists; but Sonnermann (2019) carried out a research questionnaire on how different European universities with archaeology departments teach digital humanities to their students. The results from his questionnaire could shed some light on this matter. His study identified the following:

- Courses focus mostly on basic 'digital' techniques specifically designed to learn software and equipment use.
- Field applications, data collection, data visualization and statistics were the most common topics that were taught.
- The number of students that enrol in these modules is limited and the number of instructors specialized in digital technologies depends on the size of the university.
- The theoretical background and implications of GIS did not form part of any curricula.

Sonnermann's questionnaire gathered information from 44 different European universities so the results may not be representative for the whole continent. Yet we do find interesting that our results seem to go hand by hand with some of the results he obtained in his questionnaire. In our study, information management and visualization techniques were the main uses GIS was given by archaeologists; moreover, the theoretical papers about GIS implications in archaeology are scarce. Archaeologists may be receiving GIS education as 'technician's' training. They learn how to use the software and they apply it to easy tasks (such as data management), but not the implications of its use nor its problems. Information management and recording are particularly important for archaeology and the use of GIS has contributed to ease the task. We are not criticizing this application (in fact it is one of the main potentials of GIS), but the fact that GIS is taught without considering archaeological and geographical theory. The archaeologists Lock and Pouncett (2017: 130) said the following regarding this issue:

> *'Without a nuanced understanding of the concepts of space, a detailed justification of the processes of reasoning, the role of GIS is reduced to that of representation tools'*

We believe this may be one of the reasons behind why GIS is mostly used for information management and visualization techniques in our analysed sample. There is a big gap between the application of the technology and its humanistic interpretation (Gillings, 2012; Llobera, 2012). Our review shows that papers focused on theory (*GIS & Archaeology relationship*) have decreased in proportion to the total number of publications, yet they are the papers with the most average citations. The importance of these kind of publications is out of doubt yet few authors delve into them or propose new theoretical frameworks. This could be a consequence of being less attractive publications than practical studies or because they would require learning theory derived from other disciplines such as phenomenology, for example (Llobera, 2012: 497).

Nonetheless, in the last 10 years GIS has become an integral element of the discipline and many researchers do not include GIS as a keyword. It is implied that it will be

used if the publication has some kind of spatial element. Theoretical discussions in the last decade have not revolved so much about GIS as a framework in archaeology but towards specific procedures and analyses; see for example (Gillings et al., 2020b). These publications were not captured by our selection process. This potential shift in the scope of GIS theoretical studies may indicate a higher knowledge of certain archaeologists with GIS and a hyper-specialization in certain procedures. But how widespread is this specialization among archaeologists? Does this increased knowledge and ability in certain analyses reach archaeologists from outside academia? From Sonnermann's questionnaire (2019) we can see that university curricula on digital humanities tends to focus on easy tasks, and that only a limited number of students enrol in this kind of modules. So we could argue that this specialization is not obtained, at least, at this stage.

Another issue could be related to the difficulty of using certain GIS procedures. Some methods rely on having knowledge of other disciplines or greater GIS skills. For instance, density analysis is one of the spatial analyses that has been more used by researchers in our review. It identifies visually on a map the areas with a higher concentration of a specific element. The visual results are later interpreted visually by the author. There are other GIS procedures which are more robust and capable of answering the question of clustering patterns by employing spatial statistics, such as the multi-distance spatial cluster analysis that uses K-Ripley's function. The latter was rarely employed. It involves having a higher knowledge of statistics and GIS to perform and interpret its results, while density analysis can be done by just pressing a button and looking at the visual output. This could also be the case with other more complex analyses. Either way, as was mentioned before, the use of spatial analysis (which is more complex than heritage management tasks) has increased in the last 12 years, so, does this mean that archaeologists are gaining more GIS knowledge in the last years?

We believe that the low proportion of fieldwork techniques publications (around 7%) is a consequence of a bias derived from our review. There is a significant use of GIS in the private sector, but this study focused exclusively on peer-reviewed academia papers. These papers rarely involved authors from the private sector. A limited number of authors also used GIS to engage with the public and made interesting applications of StoryMaps (e.g., Howland et al., 2020) or other open-access platforms (e.g., Welham et al., 2015).

5. CONCLUSIONS

From our review, we can conclude that studies from our sample have mostly been carried out by archaeologists or multi-disciplinary teams involving at least one archaeologist. The authors were associated, mostly, to research centres from Western Europe and North America. In Asia, most of the researchers were associated to Chinese and Indian institutions, in Oceania most of the authors were based in Australia, while in South America most papers were coming from Argentinian research centres. Africa is the continent with fewest papers associated to their institutions although there are contributions coming from South African, Moroccan and Egyptian research centres. In relation to the location of studies there seems to be a correlation between these and the location of the research centres. Nonetheless, there are countries where there was a higher number of studies in comparison to the location of the research centres. Examples of such can be found in Central America, South America, and the Near East. In these cases, most of the research, in which GIS was used, was carried out by foreign institutions.

Spatial analysis studies are the most common type of study for GIS applications in archaeology, followed by heritage management studies. From 2010 to the present day, spatial analysis studies have grown in proportion. Moreover, GIS is mostly used with visualization goals or to help gather and store archaeological data.

Within the analytical arena, predictive modelling, multi-criteria approaches, visibility and density analyses, and spatial statistics are the preferred techniques employed by researchers. The number of publications related to the development of GIS software or tools is also relevant. Reflexive studies or publications focused on theoretical development or implications of GIS in archaeology are scarce but are the most referenced type of publication in our sample. These types of papers highlight issues related to the application of these technologies, open new theoretical frameworks and can also serve to guide future studies. In our sample, the number of such publications has dwindled in proportion to the total publications in the last years. This could be caused because our selection process did not capture recent papers on this topic. Another possibility is that the number of theoretical studies is, in fact, decreasing.

From our study we have observed that a lack of theoretical development could be behind some of the problems behind the application of GIS to archaeology. Could this lack of theoretical development be behind certain general criticisms that GIS applications in archaeology have received, such as their assumed positivist approach? Or their supposed inherent relationship to processual archaeology? These criticisms were rightly done, and many archaeologists have tried to use GIS differently (Lock, Gillings, Llobera to list some examples), but this can only be achieved with a theoretical background which seems to be missing. Either way, the sample we analysed is a small one which does not comprise all publications on this topic. In that sense, our conclusions are only applied to our specific sample of analysis.

We do find relevant, nonetheless, that there is a correlation between our results and Sonnermann's questionnaire (2019) on how digital humanities are taught at archaeology departments. The points in common are the low presence of archaeological and geographical theory within the use of GIS in archaeology, and a tendency to use GIS for "easy" tasks (such as visualization or data management). Archaeologists must not only learn how to use a software tool but also understand the implications and issues that may arise from it. Integrating archaeological and geographical theory into GIS education programmes (GIS courses, university modules, etc.) could solve this issue and increase, in the future, the potential of GIS applications in archaeology.

ADDITIONAL FILE

The additional file for this article can be found as follows:

- **Appendix 1.** Data set. DOI: https://doi.org/10.5334/jcaa.104.s1

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COMPETING INTERESTS

The authors have no competing interests to declare.

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