Journal of Digital Media & Interaction
ISSN 2184-3120
Vol. 8, No. 18, (2025), pp. 45-61
DOI: 10.34624/jdmi.v8i18.39165

Simulacrum or Simulation[1] of Heritage: The Abade Case Study

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Received: February 17, 2025
Accepted: May 12, 2025

Abstract
Archaeology has undergone significant developments in recent times and is constantly adapting to the changing demands of modern society. As the contemporary world experiences constant and rapid change, the use of information technology resources is not merely a passive and complementary element of research, but an active and dynamic component in shaping the field. This article acknowledges the importance of this relationship and aims to explore the role of technology in enhancing archaeological research. Firstly, we will discuss the importance of computer simulation in archaeology as a novel way of "thinking the past" and as a training "metaphor site" for new professionals. Secondly, we argue that this new approach to archaeological science is not only a methodological advantage for predictive theses, but also an experimental platform for archaeological practice among sites. Thirdly, we bring up the potential of agent-based models and expert systems in the study of complex human and non-human systems, and in the construction of archaeological knowledge through an artificial inference engine. Finally, we provide an archaeological case study with the Abade Artificial Archaeological Site project (AAAS). In the following section, we provide a detailed account of this extensive project and demonstrate the potential applications and implications of virtual models and computer simulations in archaeology and beyond.

Keywords *Archaeological research, Information technology, Computer simulation, Agent-based models, Virtual models, Artificial Site*

1. Introduction: Computer Simulations on Archaeology

> *"With archaeological samples the randomness is often in doubt and the unavoidable lack of homogeneity due to phase sample distortion and compression has already been noted." (Clarke, 1978, p. 168)*

Computer simulation offers the unique advantage of creating "artificial worlds" where researchers can explore a vast range of scenarios and observe their outcomes. Archaeology, as an observational science, can sometimes focus too much on the technical aspects of its objects of study, leaving the complexities of human behavior to speculation. By incorporating computer simulation into archaeological practice, experimentation can become more dynamic and free researchers to adopt a more predictive approach, rather than solely relying on retrospective analysis. This allows for a more nuanced understanding of social practices and the factors that shape them over time. Computer simulation provides a third form of representation for human relationships, complementing the prevalent textual and mathematical equation-based methods in social studies. With simulations, researchers can test and evaluate hypotheses in a manner that can be repeated and refined by others. To clarify the approach, this paper first defines the role of agent-based models in archaeology, then presents the application of this method in the Abade site case study, including the model's parameters, hypotheses tested, and the results obtained.

Numerous archaeological studies have successfully applied ABM, such as the Village Ecodynamics Project in the U.S. Southwest (Kohler et al., 2005), which simulated settlement and subsistence strategies over time. Internationally, tools like NetLogo (Wilensky, 1999) and Repast (North et al., 2006) have been employed to explore past mobility, resource sharing, and conflict emergence in ancient communities. However, it is important to note that there are limitations to this approach, as the accuracy of the results depends on the parameters and data used, which may or may not directly represent real-world variables. Computer simulations not only offer a new way to theorize and understand the real world, but they are also extensively used to train professionals. In non-linear environments, simulations provide countless possibilities for experimentation and learning, making them a unique tool for understanding complex systems. In the case of human relationships, the emergence of complex systems is the key to understanding how transformations occur in groups, as no single agent is solely responsible for these changes but rather a result of the interactions among multiple agents. As a metaphor for the real world, computer simulations can be explored in various ways by archaeology (Costa, 2020, 2022).

Social systems are intricate entities that embody complex and multifaceted human behaviors. Consequently, the archaeological investigation of social practices is an ongoing endeavor that entails the continual construction and deconstruction of knowledge acquired from historical and scientific sources. As posited by Gilbert (2004), unlike the relatively predictable linear systems that pervade the physical world, human relations are largely unpredictable and subject to diverse outcomes. Thus, human societies are complex systems, and their understanding cannot be achieved solely through the study of their individual components, as is characteristic of the "hard" sciences such as physics, chemistry, or biology. Rather, the behavior of a society is said to "emerge" from the actions of its constituent units.

Moreover, human societies are dynamic entities that undergo constant transformation, making their study an ever-evolving process. Gilbert and Troitzsch (1999) have argued that the use of simulations in social sciences is a relatively new field, and despite being in use since the 1960s, the application of computers to generate simulations only became popular in the 1990s. Based on complexity theory, computer simulations are a type of virtual modeling that simplifies the study of complex phenomena. Like statistical models, computer simulations have one input and one output data system; however, they differ in their ability to incorporate "nearly" infinite variables. Therefore, the main characteristic of computer simulations is their predictive power, which can be used in combination with expert systems or independently.

It has been more than forty years since archaeologists began showing a keen interest in the use of computer simulations (Doran, 1970, 1999, 2005; Hales and Doran, 2018). However, unlike other social sciences, which have made significant progress in this area since the 1960s, the use of simulations in archaeology has remained largely stagnant in the 1980s, with only a few notable reborn in the 1990s and 2001 after all expansion (Lake, 2014). Although past critiques questioned whether human complexity could be captured in models, more recent research has shown that simulations can meaningfully represent household-level decisions, long-term demographic change, and landscape interaction (Kohler and Van der Leeuw, 2007).

However, this argument fails to acknowledge the nature of computer simulations and their great capacity for abstraction. Computer simulations are not simply mathematical models but are virtual models that can account for a wide range of variables and can be used to make predictions. Therefore, the potential for computer simulations to contribute to archaeological research should not be underestimated. While mathematical models rely on equations to represent systems, virtual models in ABM simulate the behavior of agents over time, offering dynamic interaction and visual feedback. In this context, simulations serve as both models and experiments, bridging empirical data and theoretical insight. Unlike earlier publications, this paper integrates empirical ABM application with virtual reconstruction and discusses the methodological evolution of the project from 2012 to its current digital form.

2. A new way of doing Archaeological Science?

The use of computer simulation in archaeology has been primarily limited to interpretive aspects and methodological fields, and there is a need to bring the power of formulated abstractions to the theoretical field of experimentation. By doing so, archaeology can construct a third means of scientific knowledge that goes beyond the traditional inductive and deductive approaches. This will allow for a more comprehensive understanding of complex human behaviors and relationships and provide new insights and perspectives in archaeological research. But to do this, is it also possible to adopt a dialectical approach? Dialectics involves the study of contradictions and how they interact and transform over time. In the context of archaeology and computer simulations, dialectics could be used to examine the tensions between different theoretical approaches and to explore how these approaches can be synthesized or transcended by simulations. Additionally, dialectics could be used to analyze the interaction between the simulated world and the real world, and how this interaction shapes our understanding of the past.

The current use of computer simulations in archaeology is becoming increasingly feasible as various obstacles previously identified as responsible for its disqualification are being overcome. Firstly, hardware processing capacity assisted by the development of powerful software has increased exponentially compared to previous decades, today from Quantum Computers to AIs. Secondly, the pioneering and vanguard characteristics of many simulations in social sciences are today recognized as demonstrating efficacy and legitimacy. And thirdly, many modern theories provide theoretical and explanatory support to computer simulations, thus allowing for their broader acceptance in the scientific community. On the other hand, complexity theory is the study of emergent properties that arise from interactions among agents. According to this theory, the real world is not composed of isolated segments but of relationships that emerge among different elements. These relationships are independent of each other but are simultaneously influential. It is thus incorrect to claim that a systematic study of one part can reveal the whole, because only the conjunction of its parts can be representative of the relationships that occur in the Whole.

In archaeology complexity theory has been presented also since the 1960s in the form of systems theory, however even the actual discourse of multivariate causality is only part of its epistemology. Complexity theory evokes unbalanced systems where the emergent properties are the means to grasp the whole rather than the sum of its parts; complexity theory challenges the reductionist approach that seeks to understand a system by analyzing its individual components in isolation. Instead, complexity theory emphasizes the interconnectedness of these components and how they interact to create emergent properties that are not present in any individual component alone. In archaeology, this means that studying a single artifact or site in isolation may not reveal the full picture of the society or culture it belongs to. Instead, it is necessary to consider the interactions and relationships between different artifacts and sites to gain a more comprehensive understanding of the society or culture. Complexity theory provides a framework for exploring these relationships and emergent properties in a systematic and holistic manner.

An applicable concept from complexity theory in archaeology is the "Power Law," which is also widely used in physics. The Power Law describes how the distribution of a phenomenon can occur through the accumulation of a given element by agents that already have a large quantity of it. A classic example of this is the "rich-get-richer" process in the economy. The Power Law has potential applications in archaeology, particularly in understanding the accumulation and distribution of material culture and the emergence of social hierarchies in past societies. By applying the Power Law, archaeologists can gain insights into the complex relationships between agents and the emergent properties that arise from those relationships, in a questionable and unilinear Evolution of the algorithm besides its skews.

3. ABM's Archaeology and "Black Box" Systems

Agent-based models, or ABMs, are one of the most widely used products of complexity theory in the social sciences. Several archaeological projects have demonstrated the usefulness of ABMs in creating 'virtual worlds', including simulations of urban growth, social conflict, and settlement distribution (Doran 1999; Lake 2014). These models allow researchers to test a wide variety of theories that differ from normative approaches like historical-culturalism, hypothetic-deductive models of processualism, or multiple narratives of pos-processualism. They also allow for the incorporation of ecological, gender, class, and other perspective models. Agent-based models work through successive stages of action, where the interactions among agents occur according to primary information generating changes in their environment, which in turn are fed back into the system with new information. Appearing as an endless loop, this process brings out the relationship between proprieties and establishes the dynamic of action in a complex system.

Agent-based models operate through a series of stages in which agents interact with each other based on primary information. These interactions generate changes in the environment, which are then fed back into the system with new information. This feedback loop creates a dynamic relationship between properties and establishes the action dynamics in a complex system. At each stage, agents make decisions based on their internal rules, goals, and the information they receive from other agents or their environment. These decisions can lead to emergent behaviors—such as spatial clustering or conflict—that mirror human patterns observed archaeologically, thereby offering insights into past social dynamics. By simulating the behavior of a complex system, ABMs provide a powerful tool for studying the dynamics of social, economic, and ecological systems, human or not. The broader relevance of ABM beyond archaeology is supported by its successful application in fields such as urban planning, epidemiology, and economics (Epstein, 2006), emphasizing its flexibility in modeling complex adaptive system.

Multiple-agent models, a variant of ABMs, have been identified as the most effective means of constructing social simulations on computers. These models are software collections that interact within an artificial environment, where each agent follows predetermined parameters of action based on input data, and variations can be observed. Multiple-agent models can be used to project hypothetical situations from factual data or evaluate actual situations by comparing results. However, these models, like all simulation models, are subject to two major complications. Firstly, the random character of simulations means that initial parameters will always affect predicted variables. Secondly, there is a tendency towards repetition, where similar results do not always mean identical processes. Despite these limitations, multiple-agent models are a valuable tool for exploring and understanding complex social systems. By simulating the behavior of multiple agents in an artificial environment, researchers can gain insights into the ways in which individual behaviors combine to shape larger patterns and trends.

Starting with a simpler model and gradually introducing variables to observe reactions is advised. The model can be thought of as a construction filled with objects, which can be categorized into dynamic and static objects. There is a hierarchy between these objects, and each one has its own attributes that function like variables in a mathematical equation. The next step is to establish an environment where the objects can interact in a spatial or relational form. Finally, this establishes the dynamics of the model, first between the objects and the environment, and then among the objects themselves. Each object creates a set of rules of action and reaction, which contribute to the overall dynamics of the model. By following these guidelines, researchers can develop more effective and accurate agent-based models. Because of that, it is also recommended to develop a strong research design before executing the project.

“Black Box” or expert systems in archaeology are typically composed of two main components: a knowledge base and an inference engine (Gardin, 1988). The knowledge base is where all the relevant information and rules about a particular subject are stored and organized. This includes both factual knowledge, which is the observed data related to a given topic, collected with scientific precision and technical intent, as well as operational knowledge, which is constructed through inference rules. Factual knowledge is typically derived from archaeological data, such as artifacts, structures, and environmental data, which are collected through fieldwork, laboratory analysis, and other scientific methods. This data is then organized and stored in a knowledge base, where it can be accessed and used to generate new insights and hypotheses. Operational knowledge, on the other hand, is constructed through inference rules, which are logical statements that describe how different pieces of information are related to each other. Some inference rules may be specific to the object of study, while others may have a broader application.

The inference engine is responsible for using the knowledge base to generate and reproduce intelligent constructions about domains. It does this by applying the inference rules to the available data in the knowledge base and using them to generate new insights and hypotheses. Overall, expert systems provide a powerful tool for archaeologists to organize and analyze large amounts of data, and to generate new insights and hypotheses based on that data. By combining factual and operational knowledge in a structured and organized way, expert systems can help archaeologists make sense of complex social and environmental systems in the past and gain a deeper understanding of human history and culture. Computer simulations in archaeology can contribute to both factual and operational knowledge.

In the case of factual knowledge, computer simulations can help in the collection of data related to a site or event. For example, by creating a simulation of a past civilization, archaeologists can gather data on the structures, artifacts, and environment of that civilization. This data can then be analyzed and compared with other data collected from different sources to draw conclusions about the past. In the case of operational knowledge, computer simulations can help in the development of new inference rules and scientific constructs. For example, by creating a simulation of a past event or process, archaeologists can test different hypotheses and scenarios to see how they play out. This can help them to identify patterns and relationships that may not be immediately apparent from other sources of data. The results of these simulations can then be used to develop new theories and interpretations about the past.

Computer simulations in archaeology can serve as an expert system of knowledge that can be applied in various situations to help researchers solve problems or explore new possibilities without having to redo the research. This is because computer simulations allow for the application of variables to archaeological sites or facts, which can be validated and debugged through the simulations. The simulations can also serve as a knowledge base for both factual and operational knowledge, allowing for the creation of new scientific constructs and the exercise of new actions of inference.

4. The Abade Artificial Archaeological Site Project (AAASP)

Today, in the Pireneus Mountains, approximately 125 Km from Brasília, in the municipality of Pirenópolis, the remnants of the mining village serve as the subject of this study. The Abade is a significant historical archaeological site in the state of Goiás, Brazil, consisting of the remains of a goldmine from the late nineteenth century. The mine operated from 1880 to 1887, and its village was destroyed in an attack by local villagers. This was due to water pollution as well as political and economic disagreements. An ongoing project since 2005 has been the creation of a virtual model of the historical archaeological site Lavras do Abade (Costa, 2024).

Figure 1. Lavras do Abade in 1884

Advanced planning of field activities is a crucial aspect of any archaeological research, but the objective here goes beyond the current stage of this investigation. We aim to recreate the object of study within a controlled environment that is open to interactions with the researcher. The virtual model of the Abade site was created using a combination of digital, environmental, geographic, and historical data. This data was obtained from a variety of sources, including historical documents and photographs from both public and private archives detailing the events of Abade. Adhering to Prince and Deetz's methodological principles, historical photographs of the site from 1883 were utilized to locate and identify the remnants of structures at the archaeological site. However, the outcome was not satisfactory due to excessive vegetation that hindered the precise overlay of images on the site. This was exacerbated by the distortion present in the old pictures, as well as the condition of the landscape, which was entirely devastated at that time. Significant progress was achieved by combining the data obtained from the digitalization of the remaining structures to construct a computer model of the site. The digitalization process was initiated in 2005, where a 3D scanner was employed to produce a virtual replica of the vestiges above the soil. In the month of June that same year, a week-long laser measurement scanning of building structures was conducted at the Abade archaeological site.

To conduct the scanning, a Trimble/Mensi 3D GS200 laser scanner was utilized. This scanner has a resolution of 32µrad, which means that it can capture a point up to 03 mm away at up to 100m with a precision of 1.5mm @ 50m. The capture rate of the scanner reaches 5000 pts/second and employs a Class 3R (IEC 60825-1) and Class 2 (21 CFR §1041.10) laser. The device was geo-referenced using a Z-Max receptor of dual frequency with a precision of 05 mm + 0.5 ppm and a single frequency Promark2 receiver with a precision of 05 mm + 01 ppm. The 3D scanner is a remarkable device that collects information from any object in three dimensions by using a laser to measure the distance between the object and the scanner. The software accompanying the scanner can add texture and color to the shape of the captured object with the help of digital photography. To digitize the structures in the Abade site, the equipment was placed in the immediate surrounding areas of the structures. At each capture site, the X, Y, and Z coordinates of more than 20 million dots, each with a diameter of less than 1.5mm, were collected. Additionally, each location of the scanner was geo-referenced for the creation of a topographic surface. This process resulted in the generation of a point cloud file that produced an exact replica and scale of the scanned structures within the site.

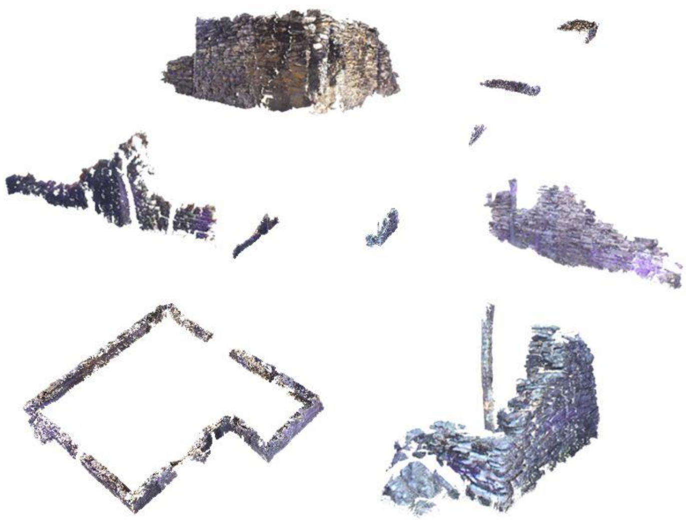

Figure 2. Point cloud of the site (2005)

Following the scanning process, a consolidation of the point cloud was conducted to verify the accuracy of the survey. In the second stage of the construction of the mathematical model of the site, the point cloud file generated from the scanning stage was imported into a software called AutoCAD Civil 3D. The software was used to create a 3D mathematical model of the site, using the point cloud file as a reference. The model was then used to create a virtual environment that could be explored and interacted with. The virtual environment was intended to simulate the real environment of the site as accurately as possible and was populated with detailed 3D models of the structures and objects present in the site, as well as natural elements such as vegetation and terrain. The virtual environment allowed for the study of the site in a controlled environment, and for the simulation of various scenarios and hypotheses related to the history of the site. A more comprehensive virtual model of the site was created using

Google SketchUp Pro Version 6.4.112 software. This involved constructing a 3D model of the entire village, incorporating both the remaining building structures from the site and those present in photographic documents of the village, which were processed in Adobe Photoshop CS8 software to correct for perspective, lens distortion, and adjust the resolution and scale of the images. One of the main goals of this photometric work was to extract three-dimensional measurements for the creation of a two-dimensional computer model.

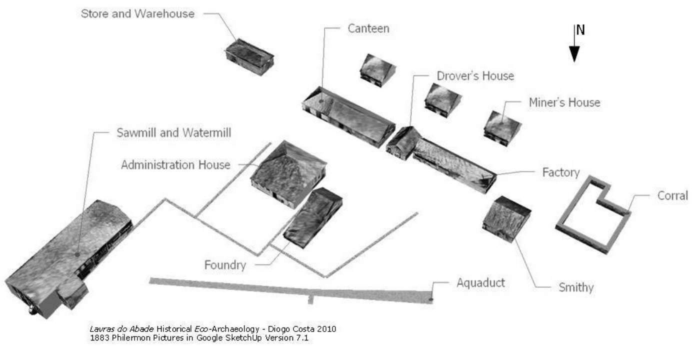

Figure 3. Virtual model of the site (2010)

The use of the virtual model for planning the field investigations allowed for a more efficient and targeted approach to the excavation process. By identifying areas of interest based on the virtual sketches and analysis of the sedimentary rock matrix, the excavation process could focus on those areas and potentially yield more significant findings. This approach not only saves time and resources, but also increases the likelihood of discovering artifacts and structures that could provide valuable insights into the history of the site. Furthermore, the virtual model allowed for the creation of animations that provide a visual representation of the site and how it may have looked and functioned in the past. This can aid in public outreach and education efforts, as well as in communicating research findings to other professionals in the field. The animations can also be used to test hypotheses about the site and its occupants, and to explore different scenarios or interpretations of the available data.

Overall, the creation of a virtual model can greatly enhance the archaeological investigation process and help to unlock the secrets of the past. The use of laser level and laser tape measure during field investigations helped to collect accurate measurements of the archaeological layers and levels at the site. The laser level Inventek V21384 was used to generate two vertical planes and one horizontal leveling plane, which enabled the measurement of height and depth of the archaeological layers. The Stanley FatMax TLM100 77-910 laser tape measure was used to record the measurements with an accuracy of ± 6mm up to 30m. The use of these instruments helped to improve the accuracy of the virtual model of the site, by providing feedback on the actual measurements of the site. In some cases, special glasses were used to view lasers under natural lighting conditions. This approach highlights the importance of using a variety of technologies and instruments to collect accurate data during field investigations and feedback to the constructed virtual model.

The field collected data during the posterior campaigns of 2007 and 2008 was included in the electronic model of the virtualization of the sub-superficial archaeological package present in the site. In 2009 a soil collection and chemical analyses of soil from around the site was planned, conducted, and tested in the virtual model. These tests were very positives about the possibilities of application of virtual models in archeological research, as well functioning as a working space for trial and error for both theoretical perspectives and practical actions in archaeological sites. The model also served as a virtual repository of all research conducted, and has therefore been an effective way to store, use and review the collected data and results. Moreover, the virtual model has allowed for the creation of new research questions, the exploration of alternative scenarios, and the development of new hypotheses. It has also facilitated communication and collaboration among researchers, as well as with the public, by providing a visual and interactive representation of the site and the research conducted. The virtual model of Abade has thus been a valuable tool in archaeological research, contributing to the advancement of knowledge about the site and the past societies that inhabited it.

The intersection between field work and the planning office forms the fundamental marks of archaeological research. The virtual model of Abade besides illustrating and animating work of exploring the archaeological site, also served to record the full suite of research activities and data collection activities. As a digital reproduction of the site an important and new stage study in the preservation of archaeological patrimony was reached: the test of research. Hitherto relegated to a later stage of data collection in archaeology, laboratory practice here also may be understood as experimentation and not only identification, analysis, and interpretation of the vestiges, and therefore attains another status.

The virtual model of Abade allowed for a more integrated approach to archaeological research, where the fieldwork and planning stages were closely linked. This integration allowed for a more efficient use of resources and a better understanding of the site (as a whole). Additionally, the virtual model provided a space for experimentation and testing, which is an important aspect of archaeological research that is often overlooked. The digital reproduction of the site allowed for a more thorough examination of the collected data and a more comprehensive understanding of the archaeological patrimony.

> *"The laboratory of an archaeological site is now also a theoretical field, where the praxis is established by the junction between the real and the virtual. In this way, the data collected at a site are not only the result of an archaeological investigation, but also the basis for the creation of a theory from the data itself. A step forward will be realized with the integration of existing data with specific software and computer simulations and comparing the obtained results with new archaeological investigations proposed for the site, feeding back in a continuous manner to form a truly expert system of knowledge about the Abade archaeological site." (Costa, 2012)*

The integration of existing data with specific software and computer simulations can indeed help in advancing archaeological research. This approach allows for the testing of various hypotheses and scenarios, which can aid in developing a deeper understanding of the site and its history. Additionally, the use of expert systems and artificial intelligence can help in identifying patterns and trends that may not be immediately apparent through traditional analysis methods. Overall, the use of technology in archaeological research has the potential to revolutionize the field and greatly enhance our understanding of the past. The Abade model also functions as a didactic tool, aligning with recent pedagogical strategies that incorporate simulations in heritage education (Champion, 2011).

5. The Virtual Life's of AAA Site

In 2012, I started another phase of research in the project, which was more practical in nature. This study involved the selection, implementation, testing, and application of various types of software for use in creating computer simulations for archaeology. The research was conducted using a systematic sequence of phases, with each computer program evaluated in different ways and possibilities. The project comprised four research phases, each with its own distinct execution and outcomes, as well as a partial assessment of each stage. The phases consisted of: Phase 1 - Researching simulation software on the internet; Phase 2 - Operating simulation software; Phase 3 - Testing simulation models of the software; and Phase 4 - Creating and testing simulation models for archaeology.

The research of simulation software on the internet was the first step in the project execution. By reading specialized literature beforehand, the decision was made to "scour" as many simulations' software related to human and biological sciences as possible. Hence, software dedicated to computational simulation in exact sciences was ignored as their profile did not correspond to what was sought by this research project. During this stage, various websites related to the topic were visited, and participation in some discussion forums about the subject, as well as email contact with certain responsible parties for the programs, was made. It is worth noting that a significant portion of the universe explored on the topic is in the English language, which is not only a global reference in scientific publication but also exhaustively used in the computing environment.

The main objective here was to establish the level of production in the area, as most of the software is a product of academic research, with a few commercial ones. Therefore, despite most academic software being free to use, their specificity ends up restricting their applicability. On the other hand, commercial software is the most adaptable to different requirements and resilient in the long term. Most of the software was obtained for free with their licenses available in the form of open-source or free software. Some were only available as a trial or limited in their time or applicability. Unfortunately, most free software is somehow outdated, which was one of the primary factors observed during their installation, and some were completely absent after reviewing this text.

The selection of software to be installed occurred primarily based on availability and compatibility, with an attempt to cover various types of programs, including both paid and free ones, as well as different operating systems such as DOS, Windows, and Linux, and various programming languages such as Visual Works, C++, Python, Java, Unix, among others. The conclusion of this first phase was the selection of 31[2] simulation software programs, which were found on various sites and discussion forums. Often, the direction of one program was given by its predecessor since the field is still in development, and study groups on the subject are still limited and not easily accessible. This initial phase of the project took approximately three months of research, during which, in addition to acquiring the software, it was also necessary to gain a basic understanding of each one.

The implementation and testing of the software acquired in the first phase of the research was conducted next. In this phase, the installation and execution of each of the 31 programs were tested, using a dedicated computer for this purpose. The computer used for the second and third testing phases was a Gateway MX3215 Notebook, equipped with an Intel® Celeron® M Processor 360 with 1MB L2 Cache, clocked at 1.4 GHz with a 400 MHz FSB. It had a memory of 500 MB DDR2 (2 x 256 MB) SODIMM (PC4300), and a 60 GB HDD (4200 RPM). The computer operated on the Windows XP environment. This phase of the project aimed to identify which software offered a more user-friendly and easily diffusible environment, as well as the limitations and potentialities of each program. Another fundamental point of this phase was to select which programs would be the best application in conducting specific simulations in archaeology.

Not all software were able to be properly installed. In some cases, limitations of the equipment, as well as incompatibility or software errors were constant issues. Additionally, some software, despite being installed without any issues, did not operate correctly or completely, making it impossible to proceed with further testing in subsequent phases. This second phase of the project took approximately six months of research, being responsible for the operability, acquisition, and installation of the programs. Of the 31 installed software, only 18 were selected for the third phase of testing. A new phase was established and aimed to evaluate the applicability of simulation models present in the software. To do so, tests were carried out with these models in different simulation options, to evaluate processing time, parameter variation and results achieved. The main observation of this phase was that not all simulation software models have the same simulation characteristics. Some programs focus more on driving physical reactions between agents, while others allow for a wider range of interactions and nuances.

It is therefore noteworthy that each tested software has its specificities and qualities, thus requiring a subsequent evaluation stage. Therefore, some software did not respond satisfactorily to the proposal of this research, especially regarding its applicability in a popular environment such as Windows and were thus disregarded for the next phase. This third phase corresponded to another six months of the research, and out of the models present in the 18 tested software, only 09 were selected for the subsequent phase. Of the 18 software programs tested previously, only 9 were selected as the best to be used in archaeological simulations. The reason for this selection was mainly because these software programs presented models suitable for the inclusion of archaeological data, as well as their easy manipulation and wide range of applications. The next phase involves applying the same model across the remaining software to determine which responses are similar or not, establishing the limits and applicability of the results. The aim of this phase is to create specific simulations for archaeology, so that it will be possible to test the different programs that best fit the project's proposal.

However, due to the revision of this text for publication, the websites of the remaining 9 software’s were revisited, and unlike what was found at the beginning of this research in 2012, ten years later, significant changes occurred in all platforms. Of this 9 selected software’s, 3 were completely discontinued without a specific date or information, 3 are stalled and haven't received upgrades since 2006, 2009, and 2015 respectively, and the remaining three software packages are up to date with updates in 2020. In this specific case of the remaining 03 programs in the analysis, 01 was for commercial use and the other 02 were for educational use.

In the end, it was determined that the ABM was probably the best model for providing feedback to the Abade Site. Agent-based modeling is a relatively new method when compared to discrete event modeling and system dynamics. As a middle range theory for archaeology, the ABM offers a multimethod platform, in which the entire model or a part of it can be composed of one method, while another part can use a different method. This flexibility allows researchers to better capture the complex interactions that occur within a system, resulting in more accurate and nuanced analyses. In archaeology, a middle-range theory is an approach that seeks to link the material remains of the past with the social and cultural practices that produced them. As suggested by Binford (1981), middle-range theory in archaeology serves to bridge the gap between empirical observation and abstract explanation. ABMs, by simulating processes linking material patterns to human behavior, offer a robust platform for operationalizing middle-range frameworks (Premo, 2006).

It is a bridge between specific archaeological data and broader anthropological or historical models. Middle-range theories aim to explain the relationships between artifacts, archaeological sites, and the cultural systems that produced them, without making sweeping generalizations about the past. They are grounded in empirical evidence and are often formulated through ethnographic or experimental research. ABMs allow for the representation of complex interactions between agents and their environment, making them well-suited for modeling social dynamics and human behavior in the past. By representing the actions and decisions of agents within a simulated environment, researchers can test different hypotheses and scenarios related to middle range theories in archaeology. Model validation remains a challenge in archaeological simulation. As Railsback and Grimm (2019) note, transparency in design and iterative testing against known archaeological cases are essential to reduce bias and increase model robustness. A summary of the model architecture, input parameters, and key emergent outcomes is provided in this paper. The full interactive simulation can be accessed online at: https://www.anylogic.com/resources/articles/the-abade-artificial-archaeological-site-project/.

6. Last Considerations: Simulacrum or Simulation in Archaeology?

Agent-based models are considered revolutionary in the social sciences for several reasons. Firstly, they do not require the old rules of equilibrium, normality, and linearity that traditional modeling approaches often rely on. Instead, they allow for the emergence of complex, nonlinear, and unpredictable behavior that is more in line with the realities of social systems. Secondly, agent-based models demonstrate the phenomenon of emergence, which means that complex patterns and behaviors can emerge from the interactions of individual agents, even though these patterns may not be predictable from the behavior of individual agents alone. This is a key feature of social systems, which are often characterized by emergent phenomena. Finally, agent-based models provide a more natural representation of social systems than traditional mathematical approaches because they simulate the actions of individual agents within the system. This allows for a more nuanced understanding of social processes, including the role of individual agency and the ways in which different factors interact with each other.

Computer simulation has three main uses in archaeology. Firstly, it can generate "artificial" data that can be used to compare or supplement actual hard data, which is always incomplete and may not fully capture the complexity of social phenomena. Secondly, computer simulations can complement analytical models, which may provide individual answers but do not work together effectively. By simulating social processes, researchers can gain a more comprehensive understanding of how different factors interact with each other to shape social outcomes. Finally, computer simulations can be used to generate analytical models when they do not exist. This is particularly useful in cases where social phenomena are too complex to be understood through traditional analytical approaches or where the available data is limited. Through computer simulation, researchers can explore different scenarios and test hypotheses in a controlled environment, allowing for a more nuanced understanding of social processes.

While computer simulations in archaeology can be used to generate results, their primary use is often to debug the analytical process. In other words, simulations can be used to test and refine analytical models by comparing the simulated data with actual archaeological data. In this sense, computer simulations can be seen as autonomous systems of knowledge or a “Black Box” that provide a tool for archaeologists to construct artificial support for the process of data interpretation. By using simulations, archaeologists can test different hypotheses, evaluate the impact of different factors, and explore alternative scenarios that might not be possible through traditional archaeological methods alone. Overall, computer simulations offer a valuable tool for archaeologists to refine their analytical processes and gain a deeper understanding of complex social and environmental systems in the past. While simulations are not a replacement for traditional archaeological methods, they can complement and enhance our understanding of archaeological data in important ways, without merely being a simulacrum heritage.

Following Baudrillard (1994), *simulacra* refer to representations that have lost their connection to an original referent, whereas simulation, as applied here, maintains a functional relationship with empirical data — not to replace reality, but to test its internal logic. Despite their significant potential, agent-based models in archaeology still face important limitations, such as challenges in model validation due to incomplete datasets, the inherent subjectivity in rule-setting, and issues related to the obsolescence of simulation software. Future research should aim to improve transparency in model design, foster interdisciplinary training, and support the development of open-access simulation platforms tailored to archaeological practice. Additionally, expanding comparative datasets and encouraging community-driven modeling efforts can enhance the reliability and interpretive value of ABMs — ensuring they serve as rigorous analytical tools rather than mere *simulacra*.

Although as mentioned earlier in this text, computer simulation was not widely accepted in archaeology during its early development (Doran & Palmer, 1995; Gilbert & Troitzsch, 1999; Epstein, 2006; Lake, 2014), this resistance was largely due to disciplinary conservatism and skepticism toward computational approaches that were perceived as too experimental or insufficiently validated. In recent years, however, the growing adoption of agent-based models and other simulation techniques has led to increasing recognition of their value for exploring complex social phenomena, particularly in archaeology (Cegielski & Rogers, 2016; Carney & Davies, 2020; Romanowska et al., 2023; Patrick, 2024). Looking ahead, the integration of artificial intelligence—especially machine learning and expert systems—holds promise for further enhancing archaeological simulations, enabling more dynamic hypothesis testing, automated pattern recognition, and adaptive modeling of past human behaviors. As these technologies mature, they may offer new methodological frameworks for interpreting incomplete or uncertain archaeological data, pushing the boundaries of how we reconstruct and understand the past.

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[1] "Simulacrum" and "Simulation" are concepts that may seem similar but have important differences, especially in the field of philosophy. A Simulacrum refers to a copy or imitation of something that already exists. It is a representation that may not have a direct relationship with the original reality but still tries to replicate it. On the other hand, Simulation is the process of imitating or replicating a system or reality. Simulation attempts to reproduce the essential characteristics of something to study or predict its behavior. Simulation can be used in various fields such as science, engineering, education, and entertainment.

[2] Agent Sheets, AndroMeta, AnyLogic, Ascape, Breve, Cormas, DEVS, Ecolab, FLAME, JAS, LSD, MAML, MATSim, MASON, MASS, MetaABM, MIMOSE, MobiDyc, Modeling4all, Net Logo, Open Starlogo, Repast, Repast Simphony, SimPack, Simpy, SOARS, Starlogo, SugarScape, Swarm, VisualBots and Xholon.