Assessing an exploratory digital environment for learning about southern African pre-colonial urbanism in space and time: a case study for Seoke, the capital of the Bangwaketse

By:

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in the

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Declaration

I, Brenda Maina declare that the dissertation, which I hereby submit for the degree Master of Science in Geoinformatics at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

SIGNATURE: ……………………………………

DATE: 27/10/2021……………………………………

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Assessing an exploratory digital environment for learning about southern African pre-colonial urbanism in space and time: a case study for Seoke, the capital of the Bangwaketse

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Abstract

The teaching of pre-colonial urban settlements in Africa has been neglected and, where present, it has traditionally relied on false concepts of civilization that played directly into stereotypes of precolonial African societies as backwards. These stereotypes are wrong and need to be challenged to transform the cultural understanding of African adaptability, resilience and accomplishments. This study, using the case study of the ancient settlement of Seoke, shows how digital environments have great potential as pedagogical tools to redress these past misunderstandings of African urbanism. Seoke was the capital of the Bangwaketse of Botswana in the 18th century. The site is characterised by the hundreds of stone walls that remain to this day. Seoke, and other archaeological sites in the region are inaccessible to the public due to private land ownership, their tough terrain and the Covid-19 pandemic. The educational potential of Seoke in exhibiting the scale, influence and organisation of Southern African settlements prior to colonization is hindered due to the inaccessibility of the site. In this study, Seoke was used as a case study for developing an exploratory digital environment for learning about pre-colonial Southern African urbanism in space and time. The environment incorporates a curation of archival material and spatial information through media such as images, videos, maps and 3D visualizations in a story map, which is a spatial data-driven form of storytelling. The exploratory environment was targeted at university students who are not deeply knowledgeable about pre-colonial southern African history or Seoke and is accessible online. The usability of the environment was studied to inform future work that includes other archaeological sites. A questionnaire and eye-tracking study was conducted to test the usability of the environment with students from three universities. A usability assessment found that users effectively learned while using the platform. Users found the various components of the exploratory environment to be well integrated and reported that they would like to use the platform again. Overall, the exploratory environment was effective in accomplishing the aim of the study, which was to create a platform for learning. Participants were able to learn while using the exploratory environment and performed well when recalling information and applying information learned. However, participants felt that the environment required technical support and prior knowledge to navigate, which influenced the usability of the platform. In future work the exploratory environment can be improved by enhancing its efficiency and by being less technical.

Key Words

story map, usability, eye-tracking, 3D visualization, pre-colonial southern Africa, Seoke, Bangwaketse, urbanism, GIS, archaeology.

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Table of Contents

Declaration ... 2
Acknowledgements ... 3
Abstract ... 4
Key Words ... 4
List of Figures ... 8
List of Tables ... 9
Definitions ... 10

Chapter 1: Introduction

1.1 Background ... 11
1.2 Problem Statement ... 12
1.3 Aims and Objectives ... 13
1.4 Study Area ... 13
1.5 Chapter Overviews ... 15
1.5.1 Chapter 2: Literature Review ... 15
1.5.2 Chapter 3: Design and Development of 3D Visualizations of Seoke ... 15
1.5.3 Chapter 4: Utilizing a Story Map as a Digital Exploratory Environment ... 15
1.5.4 Chapter 5: Usability Survey ... 15
1.5.5 Chapter 6: Eye-tracking Study ... 15
1.5.6 Chapter 7: Conclusion ... 16

Chapter 2: Literature Review

2.1 Pre-colonial Southern African Urbanism ... 17
2.1.1 Pre-colonial Urban Africa ... 17
2.1.2 Southern African Stone-walled Sites ... 18
2.1.3 Seoke and the Bangwaketse ... 19
2.2 Disseminating Archaeological Information ... 20
2.2.1 Digital Humanities ... 20
2.2.2 Mapping and GIS in Archaeology ... 21
2.2.3 Story Mapping ... 22
2.2.4 3D Visualization ... 24
2.3 Evaluating the Effectiveness of Information Dissemination ... 26
2.3.1 Learning and Confidence ... 26
2.3.2 Cognitive Overload ... 26

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2.3.3 Usability Testing 27
2.3.2 Eye-tracking 31
2.3.3 Combining Usability Testing Methods 31
2.4 Usability Testing in Digital Humanities and Heritage Studies 31

Chapter 3: Design and Development of 3D Visualizations of Seoke

3.1 Outline 34
3.1.1 Motivation 34
3.1.2 Design Characteristics 35
3.1.3 Software 36
3.1.4 Data and Tools 36
3.1.5 Scene Elements 37
3.2 Results and Evaluation 44
3.2.1 Organization of Known and Informed Spatial Data into a 3D Scene 44
3.2.2 Portrayal of the Physical Environment 45
3.2.3 Realism 47
3.3 Summary and Discussion 48

Chapter 4: Utilizing a Story Map as a Digital Exploratory Environment

4.1 Overview 50
4.1.1 Intended Users 50
4.1.2 Design Characteristics 50
4.2 Development 51
4.2.1 Applications 51
4.2.2 Spatial Data 52
4.2.3 Archive 52
4.2.4 Media Elements 53
4.3 Evaluation 54
4.3.1 Structure 54
4.3.2 The Variety of Media 55
4.3.3 Links to the Archive 56
4.4 Summary 56

Chapter 5: Usability Survey

5.1 Overview 58
5.1.1 Outline 58

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5.2 Development........ 59
5.2.1 Procedure........ 59
5.2.2 Distribution........ 60
5.2.3 Participants........ 60
5.3 Results and Evaluation........ 66
5.3.1 System Usability Scale (SUS) Scores........ 66
5.3.2 Information Retention and Confidence........ 72
5.3.3 Value and Perception........ 76
5.4 Discussion........ 79

Chapter 6: Eye-tracking Study

6.1 Overview........ 83
6.1.1 Outline........ 83
6.2 Materials........ 84
6.2.1 Equipment........ 84
6.2.2 Software........ 84
6.3 Procedure........ 84
6.3.1 Stimuli........ 85
6.4 Results and Evaluation........ 85
6.4.1 Participants........ 85
6.4.2 Distribution of Attention Across the Text and Media........ 87
6.4.3 Completion of a Task in the Archive........ 93
6.4.4 Visual and Auditory Focus Level........ 94
6.4.5 Interactivity........ 95
6.5 Discussion........ 99

Chapter 7: Conclusion

7.1 Research Summary........ 102
7.2 Future Work........ 105
7.3 Contributions........ 106

References........ 107
Annex........ 115

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List of Figures

Figure 1. Location of Seoke 14
Figure 2. The Extent of Seoke 14
Figure 3. A Stone Wall Segment at Seoke, Photographed by Brenda Maina, 2020 34
Figure 4. A Map of the Northern Clusters of Stone Walls in Seoke 35
Figure 5. Stone Wall Models Compared to a Photograph of Stone Walls in Seoke. Photograph by Brenda Maina, 2020 38
Figure 6. Reference Illustration of Tswana Veranda Dwellings, Illustrated by John Campbell, 1820 .. 39
Figure 7. Reference Illustration of a Tswana Dwelling by William Burchells, 1812 39
Figure 8. Dwelling Model in the Seoke Scene 39
Figure 9. Vegetation at the site Compared to Vegetation in the 3D Scene. Vegetation at the site Photographed by Brenda Maina, 2020 41
Figure 10. Millet Models in the Seoke Scene 41
Figure 11. Sanga Bull 42
Figure 12. Cattle Models in the Seoke Scene within the Wooden Cattle Enclosure 43
Figure 13. Midden Model in Seoke Scene 43
Figure 14. 3D Model of a Grain Bin in the Seoke Scene 44
Figure 15. Model of a Grinding Stone and Quern Stone in the Seoke Scene, Created by Anton Coetzee, 2020 44
Figure 16. Seoke 3D scene 45
Figure 17. Later Version of Seoke Scene with Vegetation 46
Figure 18. Early Version of the Seoke Scene with Vegetation 46
Figure 19. Stone Wall Models in the Seoke Scene 48
Figure 20. Early Version (left) and Later Version (right) of Dwelling Models 48
Figure 21. Visual Item in the Metsemegologolo Archive 52
Figure 22. Interactive Dwelling Visualization 53
Figure 23. Interactive Terrain Visualization 54
Figure 24. Excerpt from the Story Map 55
Figure 25. Archive Access Button in Story Map 56
Figure 26. Participants' Current Academic Year 61
Figure 27. Participants Enrolled in Courses with Some Relation to the Story Map 61
Figure 28. Participants Enrolled in Other Courses 62
Figure 29. Visualization of Participants' Registered in Other Courses at University 62
Figure 30. Modules Completed by Participants at University 63
Figure 31. Prior Knowledge About in Pre-colonial Southern African Settlements 63
Figure 32: Interest Level in Pre-colonial Southern African history 64
Figure 33. Participants' Experience Level with Story Maps 65
Figure 34. Participants' Comfort Level with English and with Using a Computer 65
Figure 35. Distribution of SUS Scores 66
Figure 36. Distribution of SUS Scores Based on the Sauro et al. (2016) Curved Grading Scale 67
Figure 37. Histograms of Participants' Confidence in Question Answers 74
Figure 38. Participants' Enlightenment Experienced from the Story Map 76
Figure 39. Pedagogical Value of the Story Map and 3D Visualization 77
Figure 40. Qualities that Made the 3D Visualization Attractive to Participants 77
Figure 41. Participants' Perceptions of the Organicness and Realism of the 3D Models 78

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Figure 42. Participant's Perceptions of Seoke and Pre-colonial Southern Africa 78
Figure 43. Participants of the Eye-tracking Study's Comfort Level with English and with using a Computer 86
Figure 44. Participants of the Eye-tracking Study's Level of Interest in Pre-colonial Southern African History 87
Figure 45. Participants of the Eye-tracking Study's Prior Knowledge about Southern African Pre-colonial African Settlements 87
Figure 46. Overall Gaze-fixation Heatmap of the 'Pre-colonial Southern African Settlements' Section 88
Figure 47. First Gaze Fixation Per Grid for the 'Pre-colonial Southern African Settlements' Section .. 89
Figure 48. Overall Gaze-fixation Heat Map of the 'Stone Walls' Section 89
Figure 49. Overall Gaze-fixation Heat Map of the 'Inhabitants of Seoke' Section 90
Figure 50. First Gaze Fixation per Grid of the 'Stone Walls' Section 91
Figure 51. First Gaze Fixation per Grid of the 'Inhabitants of Seoke' Section 91
Figure 52. Gaze-fixation Heatmap for the Interactive Dwelling Visualization 92
Figure 53. The attractiveness of the 3D Visualization as Rated by Participants (choose one or more)92
Figure 54. Participants' Rating of the Organicness and Realism of the 3D Models 93
Figure 55. Box and Whisker Plot of Participant's Task Completion Time in Seconds 93
Figure 56. Attention Levels of Participants While Viewing the Seoke Northern Cluster Video 95
Figure 57. Interactive Buttons Linked to the Archive and Interactive Visualizations 96
Figure 58. Percentage of Participants that Opened Links to the Archive and the 3D Visualization 96
Figure 59. Maximizable Image 97
Figure 60. Percentage of Participants that Maximized Images 97
Figure 61. Attributions and Legends 98
Figure 62. Percentage of Participants that Opened Attributions and Opened the Legend Bar 98

List of Tables

Table 1. Standard System Usability Scale (SUS), (Brooke, 1996) 28
Table 2. Sauro et al. SUS Curved Grading Scale (2016) 29
Table 3. Adjective Rating Scale for SUS Scores (Bangor et al., 2008) 29
Table 4. Item-level SUS Benchmark Scores (Lewis & Sauro, 2018) 30
Table 5.Cognitive Walkthrough Questions for 2D and 3D Tasks (Tromp et al., 2018) 32
Table 6. List of Spatial Data Used 37
Table 7. List of Vegetation Models from the ESRI Library that were Used in the Seoke 3D Scene 40
Table 8: Summary of the Usability Questionnaire 59
Table 9. The Gender and Ages of the Participants of the Usability Survey 60
Table 10. Item Average Scores and SUS Score Calculated from Item Average 68
Table 11. Calculated Average SUS Scores for Various Groups of Students in Descending Order 71
Table 12: Item Level Usability Evaluation of Technical Support and Prior Knowledge Needed for Participant Groups with the Lowest Average SUS Scores 72
Table 13. Percentage of Correct Answers and the Average Confidence Level of Participants 73
Table 14. Correlation Between Participants' Answer Accuracy and Self-rated Confidence Percentage 75
Table 15. The Gender and Ages of the Participants for the Eye Tracking Study 86

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List of Equations

Equation 1. Overall SUS score calculation using raw SUS scores (Lewis, 2018) 28
Equation 2. Point Biserial Correlation Coefficient (Glen, 2016)... 74

Definitions

a) (3D) Model: a digital 3-dimensional replication of an object.

b) Archive: A collection of digital archaeological objects relating to Seoke.

c) Bumpmap: A CityEngine operation that adds shadows to a model texture, creating an illusion of a raised, uneven surface.

d) Non-expert: An individual who is not a specialist or is not thoroughly knowledgeable on a subject.

e) Rule file: a piece of code written in CGA that defines a set of rules that dictate the visual and geometrical characteristics of a 3D model.

f) Scene: an organized collection of 3D models of different objects that creates a complete picture of a space.

g) Visualization: a representation of spatial information in a visual medium.

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Chapter 1: Introduction

1.1 Background

Studies about early urbanism have traditionally been influenced by Eurocentric and colonial ideologies in the identification of characteristics of the urban, and by implication, the 'advanced'. The trait-list way of thinking stated the criteria that settlements must meet to be considered urban in this regard. The criteria, created by V. Gordon Childe (1950), include social stratification, large and dense populations, centralization of surplus food, monumental public architecture, literacy and writing and the study of science, math and astronomy. These criteria describe Southwest Asia and Mesoamerican early cities well, but do not transfer to early African agglomerations (LaViolette & Fleisher, 2005; Willoughby, 2013). Thus, African urbanism was previously seen to be something that was brought over as a result of foreign or colonial influences and not something that already existed on the continent (Connah, 2001). Africanist scholars have effectively demonstrated that African urbanism and centralisation have little in common with models applied elsewhere (Connah, 2001; Haour, 2005; Macintosh and Macintosh, 1984; Pikirayi, 2001; Sinclair, 2013). Unlike on other continents, prehistoric African towns are characterised by the lack of permanence and by high mobility; no single path or clear link can be followed between the development of central places and dependence on or control over the farming hinterland. Power is focused on resources and people, with authority providing continuity, rather than by location relative to the landscape (Leyser et al., 2018). Urban spaces played the role of commercial, judicial, political and defensive centres. Spatially, they created links between surrounding sites and the landscape (Haour, 2005). Pre-colonial centralisation and urbanisation in Africa, are important themes for research on and learning of the African past, and for transforming the way that people have traditionally perceived the African landscape. For example, most students (in Africa and globally) at higher education levels are not thoroughly knowledgeable of any forms of pre-colonial urbanism on the continent.

One approach for raising awareness of pre-colonial urban settlements on the African continent is to make information available and provide learning opportunities. Online environments and the incorporation of visualizations are ideal for this, especially in instances where the site of study is physically, conceptually and archivally inaccessible. Online visualizations of spatial information have been utilised in many other parts of the world in such cases. Geospatially referenced archaeological data can be used to for maps, 3D models, virtual reality or digitised drawings used for disseminating information about a site to an audience. One such method is story mapping. Story mapping involves a spatial data-driven form of storytelling. Maps, photos, textual data and other related analytical visualizations accompanied by explanatory text can be used as tools in effectively communicating spatial information to experts and non-experts. Story mapping attaches characters and plots to data in a way that is engaging to a reader and makes the assimilation of information more natural, making it an ideal educational tool (Berendsen et al., 2018).

In other parts of the world, platforms for virtually providing viewing and learning opportunities have been developed for historical and cultural sites that are physically or conceptually inaccessible. Some projects include '*Digital Crete*' for Greece (Sarris et al., 2008), '*Fountain of the Lions*' in Spain (Tromp

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et al., 2018) and '*Visiting a Virtual Graveyard'* for the Finnish-Russian border (Häkkilä et al., 2019). These projects utilised spatial data in the creation of 3D models, 2D maps, immersive VR and spatial statistics to develop virtual learning environments for the historical sites. Examples of similar projects, especially for southern African archaeological sites are limited (Scianna & Villa, 2011).

Such educational digital environments and environments and visualizations must be carefully designed to support the learning process – for example, it is essential that available working memory capacity is not overloaded. Memory capacity can become overloaded when learners are confronted with instructional material that is laid out ineffectively. Through eye-tracking, the visual search can be mapped as a learner looks for relevant information amongst different sources (Jardodzka et al., 2017). Traditional usability testing techniques such as the System Usability Scale (SUS) identify user satisfaction and interface effectiveness and efficiency. Traditional techniques and eye-tracking all have their advantages and disadvantages but can be used in tandem as complements to each other, providing more in-depth insight into the results of the usability assessment (Wang et al., 2019).

Metsemegologolo (https://metsemegologolo.org.za/wordpress/) is a collaborative project initiated in 2019 between South African, Botswana and UK-based institutions. The digital humanities project developed an innovative multimodal archive on pre-colonial Tswana urbanisms in southern Africa by creating a digital archive and examples of digital curations of several Tswana settlements. This study aims to create an open-access, online platform that presents archival information related to early Tswana urbanism using a variety of media, within the precedent of the *Metsemegologolo* project. The project identified Seoke as one of the candidate sites out of five, for an online platform geared towards presenting archival and spatial information through an exploratory digital environment. The drive behind the development of the digital environment was in response to the educational potential of these sites considering their physical inaccessibility. Seoke was the capital of the Bangwaketse in the late 18th century, headed by Chief Moleta. The Bangwaketse broke away from the Kwena c. 1700 – 1725 and by 1780, became a regional power. Due to their expansion c. 1770 – 1790, the Bangwaketse soon controlled present southern Botswana. From 1600 to 1650 CE, Tswana-speaking communities began to develop stonewalling. Stonewalling was an expression of identity and power for the Bangwaketse (Morton, 2018; Biagetti et al., 2021). The stone wall structures, which are still present today, are the most visually apparent remains of the once regional trading power. For various reasons, this historical site is currently inaccessible to the public.

1.2 Problem Statement

Southern African pre-colonial history and urbanism is not widely known by the general public. In contrast, several historical and archaeological studies for several mega-towns in the southern African region, exist in the academic record, such as Kaditshewne, Molokwane, Marothodi (Boeyens, 2000a; Pistorius 1992; Anderson, 2009). Although boundless in their educational potential, such sites are physically inaccessible to the public in a multitude of ways. Accessibility to these sites is hindered due to private land ownership, their large size, tough terrain and their rural location. In addition, restrictions on travel due to the Covid-19 pandemic has also limited the movement of the public in general. To compound this, information about Seoke is not yet published, and as such, conceptual, academic and archival access to Seoke is also difficult for the general public. Recently, a digital archive for Seoke was built through the *Metsemegologolo* project. Platforms for virtually providing viewing

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and learning opportunities for historical or cultural sites have been developed in other parts of the world. However, similar platforms are not available for historical or cultural sites in southern Africa. Furthermore, the usability for using story mapping, 3D visualizations and archival links to teach about pre-colonial southern African history and urbanism is not known.

1.3 Aims and Objectives

The study aims to develop an exploratory digital environment for learning about pre-colonial southern African urbanism. The site of Seoke was used as a case study to assess the exploratory environment's usability to facilitate learning about pre-colonial southern African history and urbanism in space and time. An interventional design defines experiments whereby a researcher actively implements an intervention to the participants. The purpose of the study is to develop a story map with a curation of media, namely, 2D maps, interactive 3D visualizations, videos, archaeological images and archival links to act as an intervention to provide learning opportunities about pre-colonial southern African history. Seoke, as a historical site, will be used as a case study for testing the usability of a story map presented as an innovative educational platform. The results from the usability testing will inform the development of exploratory digital environments for other similar historical sites.

To do so, the following objectives were identified:

i. Develop an exploratory digital environment for learning about Seoke.
ii. Test the usability of the exploratory digital environment for facilitating learning by developing and conducting a usability survey and an eye-tracking study.
iii. Analyze the results to draw conclusions and provide recommendations on the usability of story maps to facilitate learning about pre-colonial southern African history and urbanism in space and time and to inform the further development of the platform.

1.4 Study Area

Seoke was a settlement located in the southeast of Botswana. The settlement was previously the capital of the Bangwaketse in the 18th century. The name Seoke translates to "*a large and powerful animal*" or "*something which entices or lures*". The BaKgatla baga Mmanaana ethnic group, who were raided and subjugated by the Bangwaketse, referred to Seoke as *Ntakwetoga*, which means "a surprise, something coming into view" (Matemba, 2000; Morton, 2014; Biagetti, 2021). Currently, the site is located in what is now known as "Lobatse Estates", which is a freehold farm. It is located between Lobatse town in Botswana and the South-East border with South Africa (Figure 1). Archaeological research for the site began in 2012.

From digitization using Google Earth imagery and on-site survey using a handheld GPS from November 2013 to October 2019, extensive stone walling was found at the site. Seoke spans an area of approximately 14.5 km^2 and consists of over 1180 individual stone wall segments, in addition to various other archaeological remains (Figure 2). The other archaeological evidence includes pottery fragments, grinding stones, middens, grain bins, quern stones, bones, iron implements and smelting furnaces (Biagetti et al., 2021).

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Figure 1. Location of Seoke

*Insert map: OpenStreetMap

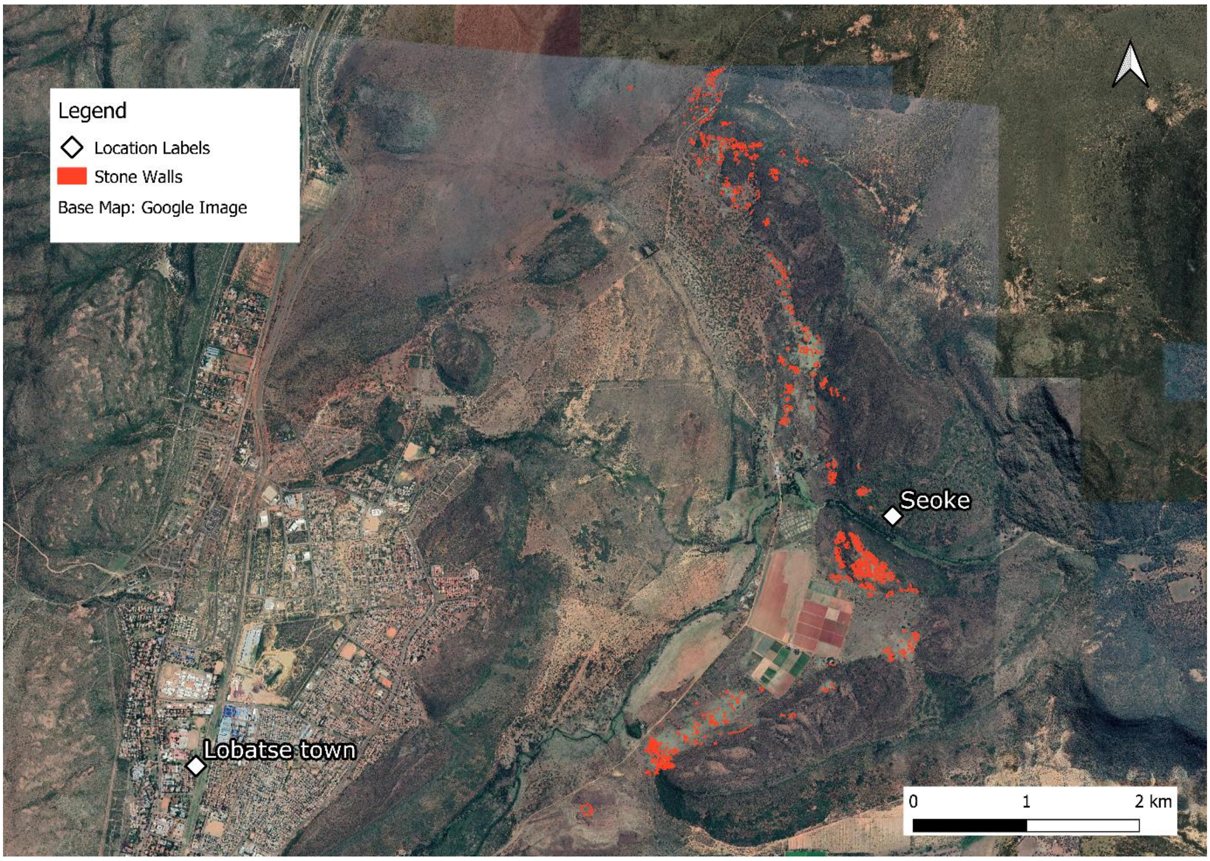

Figure 2. The Extent of Seoke

**Stone wall data was created by Stefania Merlo*

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1.5 Chapter Overviews

1.5.1 Chapter 2: Literature Review

The literature review chapter provides insight into the historical, archaeological and academic context within which information and perspectives about pre-colonial African urbanism exist and the educational material accessible to the general public. Methods for disseminating archaeological information such as 2D maps, 3D visualizations, story mapping and web-based maps will be discussed, in addition to approaches to evaluating how well the information was disseminated, such as usability testing and eye-tracking.

1.5.2 Chapter 3: Design and Development of 3D Visualizations of Seoke

This 3D visualization chapter will address the 1st objective and will discuss the data, software, methods and design choices used to develop a 3D visualization of Seoke as it likely would have appeared when it was inhabited. It will also discuss the resulting 3D models and any limitations, advantages and considerations that were discovered. The benefits of representing spatial data about Seoke in 3D as well as factors for improvement for further work will also be explored.

1.5.3 Chapter 4: Utilizing a Story Map as a Digital Exploratory Environment

This story mapping chapter will address the 1st objective. This chapter will discuss how a story map was developed that incorporates images, video, 3D and 2D elements and archival information in combination with storytelling and narration techniques. The target audience will be identified to curate the story map to their needs. The chapter will also present the completed story map and elaborate on its design choices.

1.5.4 Chapter 5: Usability Survey

The user survey chapter will address the 2nd objective and will discuss the approach to determining the usability of the final story map product through a user survey. The development of the user survey questionnaire and how it was distributed will be outlined. The usability of the story map will be evaluated considering system-level usability, user information retention and confidence, pedagogical value and user perception. The results will be presented and discussed.

1.5.5 Chapter 6: Eye-tracking Study

The eye-tracking chapter will also address the 2nd objective. The chapter will describe the eye-tracking experiment, the procedure used to conduct it and the results of the experiment. The eye-tracking experiment will analyse how users interact with the story map, considering the distribution of attention and focus, task completion time and interactivity with the functionalities of the story map. The results will be interpreted to dissect how inferences can be made about the usability of the story map.

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1.5.6 Chapter 7: Conclusion

The conclusion chapter will address the 3rd objective by summarising the knowledge gained through the results of the research and how the objectives were met by discussing the key findings of the study. Recommendations will also be made about the approach taken in this study to inform the development of exploratory digital environment for other similar historical sites.

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Chapter 2: Literature Review

2.1 Pre-colonial Southern African Urbanism

2.1.1 Pre-colonial Urban Africa

Studies about early urbanism have mainly been focused on and influenced by Eurocentric and colonial ideologies with the trait-list way of thinking stating the criteria that cities must meet to be considered urban. The trait-list is an archaeological model introduced by V. Gordon Childe (1950; 1957) that follows the progressive stages of social development - an approach by Lewis Henry Morgan (Ucko et al., 1972; LaViollete & Fleisher, 2005). The criteria are based on the sociological definition of cities by Louis Wirth (1938) and are exclusionary in addition to being very static. The criteria include social stratification, large and dense populations, centralization of surplus food, monumental public architecture, literacy and the study of science, math and astronomy. The criteria well portray Southwest Asian and Mesoamerican early cities but do not transfer to early African settlements. It was believed that urbanism was impossible in Africa, as the continent has favourable and unlimited land for agriculture, and has a culture of subsistence economies, which removes the need for developing social complexity. In addition, there was a thought that people in African societies did not try to accumulate wealth and capital through controlling land and production, which would also limit the need to develop hierarchical societies. Thus, African urbanism was previously seen to be something that was brought over as a result of foreign or colonial influences and not something that already existed on the continent (LaViolette & Fleisher, 2005; Connah, 2001).

Alternatively, the functional approach was developed in response to the downfalls of the trait-list approach. While the trait-list approach focused on what a settlement is to characterise it as urban, the functional approach focuses on what a settlement does (LaViolette & Fleisher, 2005). The functional approach focuses on the role that institutions have in urban centres for both the urban and rural populations. This allows urbanism to be linked to rural-urban interdependence. In other words, the function of urban centres was for conducting specialised functions in relationship with the broader hinterland. Thus, the functional approach is dynamic in comparison to the trait-list, as it studies the relationships between the different components of a society and how they are integrated. Using this approach, an urban community would be one that was primarily commercial but also included fortification, a system of laws and a court. They were based on economic strategy and control of autonomous political functions. From a locational or spatial perspective, urban centres connect individual sites with their surrounding landscapes. From an ecological perspective, regional systems were connected to their environmental settings. The approach does still have its pitfalls, as it assumes that urban settlements emerge due to the shared interests of its inhabitants, side-lining the debates or conflicts within cities (LaViolette & Fleisher, 2005).

Africanist scholars have effectively demonstrated that African urbanism and centralisation have little in common with models applied elsewhere (Connah, 2001; Haour, 2005; Macintosh & Macintosh, 1984; Pikirayi, 2001; Sinclair, 2013). Unlike on other continents, prehistoric African towns are characterised by the lack of permanence and by high mobility; no single path or clear link can be

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followed between the development of central places and dependence on or control over the farming hinterland. Power is focused on resources and people, with authority providing continuity, rather than by location relative to the landscape (Leyser et al., 2018). Consequently, early African urbanism is characterised by the functions and roles that institutions within the urban space had in relation to the broader rural community and hinterland. Urban spaces played the role of commercial, judicial, political and defensive centres (Haour, 2005). Overall, early African urban settlements could be categorized by characteristics such as their scale and their title as the capital of an ancient state, often encompassing elite residences and monuments. The settlements acted as political, administrative and spiritual centres. They facilitated the mining of gold, copper, stone and ores and the long-distance relationships required for their trade (LaViolette & Fleisher, 2005).

2.1.2 Southern African Stone-walled Sites

Pre-colonial centralisation and urbanisation in Africa, are important themes for research on and learning of the African past, and for transforming the way that people have traditionally perceived the African landscape. Stone walled sites can be found in southern Africa in the regions across Zambia, Zimbabwe, Botswana, Mozambique and South Africa. Occupied by various Bantu-speaking groups, stone-walled sites first appeared in the 13th century (Huffman, 2007; Biagetti et al., 2021). Studies of stone-walled sites in the southern African region have found that these sites fall within two patterns – the Zimbabwe Pattern and the Central Cattle Pattern (CCP), which are models used to describe the spatial arrangement of settlements within the southern African Iron Age. The theoretical approach of modelling the spatial organisation of settlements has value in that it creates a framework for studying the relationships and worldview within a society. Studies of human behaviour have found that societies section off and assign unique activities to their physical environment which in turn informs the social behaviour around it. (Huffman, 2001; Badenhorst, 2009; Biagetti et al., 2021).

Mapungubwe (1075 - 1220 CE) and Great Zimbabwe (1100 - 1550 CE) are the most well-known and largest urban settlements in southern Africa prior to colonialism. The stone walls in Mapungubwe and Great Zimbabwe both fall within the Zimbabwe Pattern. The study of these settlements provides important insight into African urbanism outside of the definitions derived from Eurocentric views (Manyanga et al., 2010). These settlements held the characteristics of an early southern African urban settlement and were secondary in origin, as surplus resources and trade relations with other societies afforded these settlements the opportunity to promote social complexity (Huffman, 2009). Although these settlements are well known, they are not yet explored. There are aspects about the settlements such as their material culture, commoner residences, the production and distribution of goods and the exact time and reasons for their decline that are still being studied (Pikirayi & Chirikure, 2011; Chirikure & Pikirayi, 2008; Huffman & Vogel, 1991; Pikirayi, 2013).

Other examples of early settlements include sites in South Africa such as Moor Park in Kwa-Zulu Natal, which dates from the 13th to the 15th centuries; clusters of stone walls near Ntsuanatsatsi hill in Free State province, which dates to the 16th century; and the settlements in the Pilanesberg-Magaliesberg region that dated to the mid-18th century (Biagetti et al., 2021). These stone wall sites

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are categorised as CCP settlements, which is a settlement model derived from the settlement patterns of Nguni and Sotho-Tswana speakers (Huffman, 2001; Badenhorst, 2009). CCP settlements were often inhabited for one or two generations, with a large number of stone structures and thin archaeological deposits with a scarcity of artefacts within them and even on the surface (Biagetti et al., 2021). The stone structures in CCP settlements often have similar physical shapes and structures, which makes identifying their specific use during inhabitation almost impossible, except for distinguishing between livestock and dwelling enclosures. Instead, excavations of middens (storage pits) and stock enclosures are conducted to extract artefacts that are used to chronologically sequence the site (Huffman, 2001; Biagetti et al., 2021).

2.1.3 Seoke and the Bangwaketse

Seoke (Ntakwetoga) was the capital of the Tswana-speaking Bangwaketse in the late 1700s, headed by *kgosi* (chief) Moleta. The pre-colonial settlement was located near what is now Lobatse town in the South-East District of Botswana. Having broken away from the Kwena in the early 1700s, by 1780, the Bangwaketse expanded rapidly, and their influence was felt across southern Botswana and in areas almost 200 km away, covering regions such as the North West and Northern Cape provinces in present-day South Africa. Their strength came from their military units called *mophato*, made up of young men, armed with iron spears and axes. They raided for cattle in the region and absorbed many neighbouring groups (Morton, 2017; Morton, 2018; Biagetti et al., 2021).

The archaeological site is currently inaccessible to the public as it is located on private land. Coupled with the history of the Bangwaketse's dispossession and displacement from their land (Brown, 2020), Seoke had been forgotten for centuries until it and other related sites were rediscovered recently. As part of archaeological research in southeast Botswana that started in 2012, Seoke and other sites related to Moleta's rule have recently been recorded by Morton and Merlo (2015) through an amalgamation of topocadastsral information, remote sensing, survey and oral traditions (Biagetti et al., 2021).

From 1600 to 1650 CE, Tswana-speaking communities began to develop stonewalling. While extensive studies have been conducted for stone-walled sites in present-day South Africa (Anderson, 2009; Boeyens, 2000a & 2000b; Pistorius, 1992), stone-walled sites in Botswana have not been studied as extensively. Stonewalling was an expression of identity and power for the Bangwaketse but was also theorised to be a product of the scarcity of wood in the area. Wood was a limited resource that was more crucially needed for smelting and cooking. The stone walls, which are still present today, are some of the most visually apparent material remains of the settlement (Morton, 2018). The extensive, distinct but interlinked clusters of stone walls at the site vary in size and cover the foot hills of the site

Seoke falls within the Central Cattle Pattern (CCP) settlement model and is, in fact, one of the most extensive Late Iron Age, CCP stone-walled sites in the Botswana-South Africa region. Cultural beliefs such as leadership passed down to male descendants, patrilineal beliefs about procreation and bridewealth in cattle are key principles in the CCP model. Regarding the organization of space in CCP

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settlements, cattle were centrally positioned and there was a clear division between male and female occupied spaces (Huffman, 2001; Biagetti et al., 2021). Archaeological evidence has found that the physical characteristics of CCP settlements include stone walls, storage pits, cattle kraals, grain bins, central burial zones and ceramics (Huffman, 2001; Badenhorst, 2009).

Unlike stone wall sites in the Zimbabwe Pattern such as Mapungubwe and Great Zimbabwe, stonewalling in CCP settlements are not limited to elite spaces. Rather, stone walls are used to separate households, people, cattle and the surrounding environment (Huffman, 2007; Biagetti et al., 2021). Apart from the stone walls, other archaeological objects and evidence have been found at the study site. The evidence includes middens, grain bins, grinding and quern stones, pottery fragments, bones, iron implements and smelting furnaces. Evidence of cattle kraals and sliding doors have been found as well. (Biagetti et al., 2021).

2.2 Disseminating Archaeological Information

The abundance and nature of pre-colonial southern African settlements and their associated materials, whilst well documented, understood and published in the research arena (see for example Anderson, 2009; Boeyens 2000, Morton 2014) has not been used to teach concepts of African indigenous development of urbanism, particularly at school level. This section will explore some of the digital dissemination approaches for archaeological information that can accommodate geospatial information as well, analogous to a virtual 'field trip'.

2.2.1 Digital Humanities

Digital humanities is the intersection between digital technologies and academic work in the humanities in a manner that involves interdisciplinary collaboration (Drucker et al., 2013). The digital humanities work to apply traditional approaches used in the humanities in the digital era. Text-based traditional approaches have moved to transmedia, graphical and design-based approaches (Burdick et al., 2012). In a 2020 study by Benito-Santos and Sánchez of the current state of the field of digital humanities, the keywords of academic papers in the field were analysed. The study extracted referenced works from a dataset of over 1900 publications to identify and visualize the leading authors, citation patterns, keywords and prominent themes in the field using algorithms. The study found that the frequency of keywords relating to the application of GIS in archaeology ranked relatively high in the digital humanities. These keywords include those such as '*map*', '*spatial*', '*3D*', '*media*' and '*archaeology*'. The keywords relating to GIS were also found to have close connections with other keywords in the digital humanities, with these connections projected to become more central and important in the fields in the future. The GIS keywords themselves, however, are not closely linked to each other, showing that they are separable and do not form a coherent cluster in and of themselves. This means that academic papers with GIS-related keywords involve research wherein GIS is applied in different themes of research instead of GIS being a theme in itself.

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2.2.2 Mapping and GIS in Archaeology

Mapping is an integral practice in archaeology. From the process of survey and excavation to communicating information in publications, mapping is utilized in the form of survey and site maps, profile drawings and other related products. (Warner-Smith, 2020). The application of Geographic Information Systems (GIS) in archaeology began in the 1980s and has since then grown as technology improved. The ability to integrate both temporal and spatial data through GIS is suitable for the analysis of the spatial context of historical data (Djindjian, 1998; Scianna and Villa, 2011).

The application of GIS in archaeology can be used as a means of transcribing historical information in a manner that is better suited to a target audience. Not all forms of historical and archaeological data available are best suited for helping a general audience understand and conceptualize archaeological information, sites and features. A GIS can be used to visualize relevant information in a manner that is easier to process (Ardissone and Rinaudo, 2005). Archaeological and historical data characteristically have temporal and spatial attributes. Comparatively, and unlike other methods such as spreadsheets or specialized drawings, GIS software can support the digital viewing, manipulation, analysis, presentation, distribution and storage of temporal and spatial information in addition to the spatial and temporal relationships between data points (Scianna & Villa, 2011). Archaeological and historical information can be represented as point, line or polygon vector abstractions or, simple image rasters or multispectral rasters (Djindjian, 1998). As an analytical tool, GIS links graphical information from maps and photographs, namely feature locations, with feature descriptions or attributes. By creating data links in this manner, relationships between not only data points but data sets can be created. Associating attributes to data points such as map features and creating relationships between map features can yield undiscovered characteristics about archaeological sites, structures or objects (Neuber, 2004).

GIS data based on cultural heritage and history is often extracted from historical documents and archival data that has to be interpreted by a specialist. Different interpretations may skew the accuracy of the data. As such, specialists must take special care to add the relative accuracy of the spatial data as metadata. Recording the time at which data was created is also an essential attribute of metadata. The recording time will provide insight into the knowledge that was available at that time that would influence the interpretation of historical documents (Ardissone and Rinaudo, 2005).

Intra-site GIS is a Geographic Information System for excavations and site-based analysis. In an archaeological context, it involves identifying the spatial correlation between archaeological artefacts to make inferences about the role that the artefacts played in settlements and societies they existed in. Furthermore, 2D maps, 3D modelling, virtual reality and digitised drawings, can be supported by archived archaeological data. GIS can also be applied in cultural research management whereby the protection, management, and promotion of a cultural heritage site is supported by a GIS (D'Urso et al., 2017; Macháček et al., 2003).

GIS in archaeology has been implemented in many other parts of the world in cases where historical sites are inaccessible, either physically (i.e., site closure, remote location or a lack of archaeological

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evidence due to excavation) or conceptually. Some projects include '*Digital Crete*' for Greece (Sarris et al., 2008), '*Fountain of the Lions*' in Spain (Tromp et al., 2018), the '*Çatalhöyük Research Project*' for a Neolithic settlement in present-day Turkey (Hodder, 2020; available at: https://www.catalhoyuk.com/) and '*Visiting a Virtual Graveyard*' for the Finnish-Russian border (Häkkilä et al., 2019). These projects utilised functionalities such as 3D modelling, 2D maps, immersive VR and statistics in the project. Examples of similar projects, especially for southern African historical sites are limited (Scianna and Villa, 2011).

2.2.3 Story Mapping

Story mapping involves a spatial data-driven form of storytelling. Maps, photos, textual data and other related analytical visualizations accompanied by explanatory text can be used as tools in effectively communicating geospatial information to experts and non-experts. Story mapping attaches characters and plots to data in a way that is engaging to a reader and makes the dissemination of information more natural, making it an ideal educational tool (Berendsen et al., 2018).

The use of story maps as a tool in an educational setting has been tested in several studies and have shown favourable results from both the educator and learner's perspectives. In a study by Strachan and Mitchell (2014), the perception of educators towards story maps was studied. The 42 educators consisted of K-12 (kindergarten to grade 12) teachers as well as independent educators. The participants were teachers of a variety of subjects. The participants were asked to attend workshops where they received training. They were first asked about their prior knowledge of GIS, then presented with a PowerPoint about story maps. The training covered the entire process of creating an ESRI story map, from making an ArcGIS online account, creating a web map, adding data to the web map and sharing the final product. Participants were then asked to fill out a survey with demographic information and Likert scale questions about the ease of use and interactiveness of story maps and the expected student enjoyment from the story maps. Participants were also asked some Likert scale questions about the challenges they experienced while creating a story map, focused on the ease of navigation through ArcGIS online and enjoyment level while making the story map. The results found that 95% of participants found story maps to be user-friendly and 98% found story maps to be engaging and interactive. Expected student enjoyment also received a good score, with 87% of participants believing that students will enjoy the story maps (Stachan and Mitchell, 2014). As the research is a case study on developing a digital platform to facilitate teaching and learning, the tools and methods must be suitable for recreation in future iterations of the work. Because the participants in the study included those who are not familiar with GIS, the positive feedback is valuable.

A separate study by Groshans et al. (2019) studied the perception that learners had of story maps. The study compared a story map with a PowerPoint presentation which is a mainstream and common tool used in teaching. Both the story map and the PowerPoint covered the same topic, "Soil Forming Factors: Climate", which is a topic that is covered in a Soil Information Systems module at Clemson University. The participants of the study consisted of two groups. The "comparison" group

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were past students who had already taken the course in the past and were taught using a PowerPoint presentation. The second group ("test" group) were students who were in the process of taking the course. The second group was taught using the story map. The story map featured web maps that covered the topics of climate and soil temperature and moisture regimes. The web maps were supported by tables and figures as well. Each topic in the story map had quiz questions that matched the quiz questions that the "comparison" group had to answer when they were taught the course through PowerPoint presentations in the past.

The "test" group participants were asked to fill in a pre-activity questionnaire that collected their demographic information before learning about the topic using the story map as part of a one-hour laboratory exercise. After completion, participants were asked to complete another questionnaire about the story map, which included questions about intuitiveness, effectiveness and comfortability of the story map. They were also asked to compare story maps to PowerPoint presentations on factors such as quality, ease of use and enjoyment. It was found that the story map worked better for helping learners conceptualize pictorial models and for reinforcing the information that they learned. Although there was no statistical difference between the quiz scores of the "comparison" and "test" groups, learners experienced a greater sense of confidence (Groshans et al., 2019).

In developing a story map, care needs to be taken in the manner in which information is represented. The misrepresentation of information and bias is possible in the narration and the web maps. Narratives can take on different degrees of scientific or philosophical tones depending on the topic at hand (Stephens & Richards, 2020). More relatedly, most canonised narratives of history present stories of unequal distributions of power. Texts have the power to dislodge alternate narratives, positioning the reader to identify with powerful characters while the voices of the displaced, dominated and silenced remain unarticulated (Said, 1975; Dube, 2000).

Epistemological discussions of the potential issues arising from representation, objectivity and subjectivity in spatial archaeological information disseminated using GIS, have been held since the 1980s. Nevertheless, as mapping is an integral part of archaeology, instead of moving away from GIS, a move has been made to actively pursue post-colonial, feminist and participatory approaches to mapping and GIS (Warner-Smith, 2020). In story mapping, the researcher has the role of transforming a story into spatio-temporal units, then into cartographic objects. In this process of transformation, the story map's developer's role and choices should be as minimal as possible (Caquard & Dimittrovas, 2017). Rather than having the voice of the researcher as the sole narrator in the story map, the voices of the communities and descendants of the topic of discussion should be at the forefront (Warner-Smith, 2020). Presenting historical objects - i.e., photographs, maps, texts and quotations that yield information - as a simple succession of events rips the objects out of their historical context. By additionally presenting the stories, emotions, inventions and scenes that historical objects emerged from, the character of the individuals who produced them can be revealed (Denzin, 2006). One spatio-temporal example is the utilization of original territorial boundaries and place names prior to colonial influence (Warner-Smith, 2020).

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2.2.4 3D Visualization

3D visualization in GIS is the rendering of a 3D scene using a 2D computer screen. The resulting scene creates a picture of a physical space that with the use of shadows, texture and overlap, appears to have depth. Although commonly associated with 3D visualizations, qualities such as immersiveness, interactivity and level of realism can vary greatly amongst different types of 3D visualizations. Not all 3D visualizations are hyper-realistic or immersive; 3D plots or charts, shaded relief maps and non-photorealistic 3D objects fall into this category (Cöltekin et al., 2016). The development of new technologies for the capture of geospatial data has in turn called for the expansion of approaches for its visualization (Djavaherpour et al., 2017). While most GIS-based educational practices are limited to 2D mapping and analysis, 3D geovisualization facilitates learning about environments in their entire spatial arrangement. By visualizing the dimensions of objects in an environment in the x, y and z axes, communicating the complexities of a physical environment becomes easier, even when the visualizations are viewed digitally on a 2D screen (Yin, 2010). Visualization of geospatial data in 2D is often applied to abstract, ephemeral, quantitative and qualitative data. Consequently, the visualization of geospatial data in 3D is an innate approach when the visualized objects have 3-dimensional characteristics and the visualization intends to present those dimensions authentically (Seipel & Carvalho, 2012).

A 3-dimensional approach to disseminating information facilitates a wider understanding of information beyond fieldwork and attracts a wider audience. The effectiveness of 3D visualization in communicating and conceptualizing spatial information has been tested in several teaching applications, such as in urban planning (Yin, 2010) chemistry (Astuti et al., 2020) and archaeology (Lecari, 2017) and is useful when the topic of study is not physically accessible in the real world and helps with stimulating critical thinking skills. Consequently, in a study by Loschky et al. (2010), it was found that 3D visualizations with higher realism are more effective when presented for tasks such as object recognition and information retention. A 2007 study by Wang et al. investigated learner's responses to information presented in 2D and 3D with participants who were university students. The participants for this study were required to complete a pre-test, a learning lesson where participants were randomly assigned content in 2D or 3D through an online platform, and a post-test. The learning lesson was self-regulated but had a maximum allotted time of 35 minutes and its content was the same, regardless of whether it was presented in 2D or 3D. Although limited by the small sample size of 23, the study revealed that participants in the 3D group performed higher in the post-test than the 2D group. Also, participants in the 3D group showed improvement from the pre-test scores compared to their post-test scores, whereas the participants in the 2D group performed worse in the post-test.

The process for designing 3D geospatial visualizations can be divided into three design aspects. The modelling aspect defines the geometric characteristics of the 3D visualization. These characteristics then inform the symbolization aspect, which defines the appearance of modelled objects, such as shape, texture, abstraction and generalization. Lastly, the visualization aspect defines the parameters within which models are displayed, such as viewing angle, camera settings, incident lighting and atmospheric effects (Harberling et al., 2008).

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3D visualizations can be presented at three different varieties of realism, as first introduced by Hagen (1986). The first variety is physical realism, whereby the visualization provides the same visual stimulation for the viewer as a scene in the real world. The visualization, therefore, must provide the same spectral irradiance values as the real-world scene; the portrayals of the shapes and textures of objects must be accurate and even the light energy produced by the display monitor must be equivalent to that of the real-world scene. The criteria for a visualization to be considered physically realistic are quite stringent and can only be achieved in special conditions. The second variety is photorealism, which, in layman's terms, means that a visualization must be indistinguishable from a photograph of a real-world scene. For a visualization to be considered photorealistic, it must garner the same visual response as a real-world scene for the viewer, although the light energy produced by the visualization and the scene is different. The last variety of realism is functional realism, whereby the visualization and the real-world scene deliver the same visual information. To be considered functionally realistic, a visualization must reliably convey information about the properties of objects, such as dimensions, materials, size and location, to the viewer (Ferwerda, 2003).

In archaeology, 3D modelling is a form of data capture, digital documentation, virtual reconstruction and digital communication, all of which can be achieved in increasing complexity as technological capabilities exponentially improve. 3D modelling technologies have been utilised in several projects in the fields of 3D archaeology, excavations and reconstructions, 3D web and 2.5D GIS (Sanders 2011; Petrovic et al. 2011; Katsianis et al. 2008; Levy et al. 2010), all of which have different aims and objectives but mainly aimed to present static visualizations of sites or artefacts (Forte, 2014). In the 3D visualization of archaeological geospatial data, the term reflexivity describes the process of examining archaeological actions and assumptions and their effect on the community, both archaeological and local. Engaging in discourse from various perspectives is one such method of reflexivity. The illustration and visualization of objects and places from the past have been subject to reflexive discourse, however, there is a consensus that the practice has epistemic value, especially when coupled with reflexivity. 3D visualizations should not be seen as recreations of absolute truths but rather be flexible to interpretations, changes in perceptions and changes in hypotheses (Lecari, 2017). On the other hand, 'flexible' visualizations of data can also be interpreted as transient and unstable, often created to develop an impactful but ephemeral product for a research project, rather than as an academic contribution. Value and knowledge must be gained from the design process, which should serve the purpose of exploring the functionality, replicability and practicality of the visualization tools, serving as contributions to research. Contrary to the scientific approaches utilized in the creation of visualizations, qualitative and interpretive knowledge can be produced in the process, which can lead to changes in academic arguments and hypotheses (Forte, 2014; Hinrichs & Forlini, 2017).

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2.3 Evaluating the Effectiveness of Information Dissemination

Approaches for the dissemination of educational information must be carefully designed to support the learning process. This section will discuss important factors that can positively or negatively impact learning and the tools and norms that can be used to evaluate the usability of a system designed to facilitate learning.

2.3.1 Learning and Confidence

Learning is a perpetual activity experienced throughout life; one that results in changes in abilities, knowledge and perspective, caused by external interventions. Motivation (both internal and external) is an important contributor to learning, which in turn is influenced by confidence. Confidence can be affected by 3 key variables, as theorized by Keller (1979) in Keller's ARCS (Attention, Relevance, Confidence and Satisfaction) model. The key variables for learner confidence include the learning requirements, opportunities for success and personal control, all of which affect the learner's expectations for positive results when expending effort and risk while learning (Moller, 1993). Confidence is related to one's own beliefs in their abilities – a psychological trait that is related but separate from one's personality and abilities (Shoemaker, 2010).

In a study conducted with student teachers transitioning from learners into teachers, confidence was found to have positive emotional, cognitive and performance effects. Emotionally and cognitively, it was found that participants in this study associated confidence with comfort, self-assurance, happiness, being relaxed and lacking fear. Regarding performance, participants associated confidence with ability, competency, composure and effectiveness (Norman & Hyland, 2003). When negative feelings are felt – unlike the positive feelings felt when confident – the time invested in learning and the amount of knowledge gained from learning is reduced. This is because avoidance attitudes take up some of a learner's cognitive resources, limiting how much the learned material is processed (Kremer et al., 2019).

2.3.2 Cognitive Overload

Cognitive Load Theory (CLT) is a framework for exploring how learners process information to inform instructional design (Paas et al., 2003). The mental burden when processing a difficult task that requires a lot of mental resources (i.e., auditory, visual, etc.) is called cognitive load (Hossain & Yeasin, 2015). Cognitive overload, therefore, occurs when an individual is faced with mental work that exceeds their mental abilities (American Psychological Association, 2020).

One such example is the cognitive overload that can be caused by 3D. Cognitive overload is known to be an issue in the manipulation of dynamic 3D models, immersive 3D games and hypermedia 3D learning environments, especially for learners with a low spatial ability (Berney et al., 2015; Gerjets & Scheiter 2003; Paas et al. 2003; Huk, 2016).

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2.3.3 Usability Testing

When developing a digital platform, evaluating the human reaction to it is crucial. Identifying the factors that make a digital platform usable and useful have been studied from many perspectives using various approaches. Usability testing relies on user response and feedback on prototypes to iteratively refine a platform, maximising the platform's efficiency, effectiveness and user satisfaction. The feedback can give insight on how the platform is used, how easy it is to use and how easy it is to learn to use (Armaselu & Jones, 2017). For teaching and learning, special attention should be placed on providing a platform that minimises user frustration and anxiety, as these negative responses can overshadow any learning that was done. Usability testing often requires participants to complete several platform navigation-based tasks and uses metrics such as the accuracy and time taken to complete a task as a measure of usability. However, the tasks in a usability test for a platform focused on learning should be based on information retention. As such, the usability test should answer the questions; 'how effectively did the user learn?', 'how efficiently did the user learn?' and 'how satisfied was the user while learning?' (Van Nuland et al., 2017; Kremer et al. 2019).

2.3.3.1 System Usability Scale

The System Usability Scale (SUS), developed by John Brooke (1996), is a questionnaire that is considered the standard approach for assessing usability. The questionnaire is a usability testing tool for industrial systems and can be applied for testing the usability of systems such as apps, mobile devices, websites, operating systems and more. Usability is broken down into 3 components - effectiveness, efficiency and satisfaction. Effectiveness is a measure of whether users can complete tasks using a system. Efficiency is a measure of the energy and resources spent while using the system to complete tasks. Lastly, satisfaction is a measure of how comfortable users are while using a system to complete tasks. These 3 components work in tandem to elevate each other. The SUS was designed to determine participants' subjective perceptions about the usability of a system, keeping effectiveness, efficiency and satisfaction in mind. (Brooke, 2013).

The SUS uses statements (referred to as items) that can be scored on a 5-point based system ranging from 1 = *strongly disagree* to 5 = *strongly agree.* The SUS can be seen in Table 1. Having been developed in the 1980s, the questionnaire made up of 10 items has become a popular method for post-study usability testing for its simplicity while providing quick and reliable results. The lack of fees attached to its use also propelled its popularity, as the only requirement is to cite the source on the SUS in any published work. The SUS is very flexible to adjustments such as the omission of an item or changing the wording to fit the context of a specific study (Lewis, 2018). The scoring system for the SUS should be measured with care as although the 5-point scoring system seems simple, the questionnaire items themselves alternate between positive and negative tones for odd and even-numbered statements respectively. An example of an item with a positive tone would be 'I thought the system was easy to use' whereas an example of an item with a negative tone would be 'I found the system unnecessary complex'. As the scoring system remains fixed regardless of the tone of the item, adjustments must be made to the raw score when calculating the overall SUS score. A value of 1 should be subtracted from the odd-numbered item scores to adjust it. Even-numbered item scores should be subtracted from 5 to adjust it. Alternatively, Equation 1 can be used to calculate the overall

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SUS score using the raw values. Although the overall SUS score will be a value ranging between 0 and 100, it is not a percent value (Lewis, 2018).

Table 1. Standard System Usability Scale (SUS), (Brooke, 1996)

The System Usability Scale Standard Version		Strongly Disagree				Strongly Agree
1.	I think that I would like to use this system frequently	1	2	3	4	5
2.	I found the system unnecessarily complex	1	2	3	4	5
3.	I thought the system was easy to use.	1	2	3	4	5
4.	I think that I would need the support of a technical person to be able to use this system.	1	2	3	4	5
5.	I found the various functions in this system were well integrated.	1	2	3	4	5
6.	I thought there was too much inconsistency in this system.	1	2	3	4	5
7.	I would imagine that most people would learn to use this system very quickly	1	2	3	4	5
8.	I found the system very cumbersome to use	1	2	3	4	5
9.	I felt very confident using the system	1	2	3	4	5
10.	I needed to learn a lot of things before I could get going with this system	1	2	3	4	5

Equation 1. Overall SUS score calculation using raw SUS scores (Lewis, 2018)

$$SUS = 2.5(20 + \Sigma(SUS01, SUS03, SUS05, SUS07, SUS09) - \Sigma(SUS02, SUS04, SUS06, SUS08, SUS10))$$

On its own, the SUS score has no context of meaning as to whether the value is good or bad. As such, a curved grading scale was developed by Sauro et al. (2016), using a large sample data set of SUS scores from multiple sample usability tests, as seen in Table 2. The 50th percentile score was calculated to be a SUS score of 68, and an overall SUS score of 80 is seen to be the goal for proof of above-average system usability.

Another approach for interpreting overall SUS scores is the adjective rating approach developed by Bangor et al. (2008) (Table 3). This approach was developed to provide a way to group SUS scores in a way that was easier to understand. The adjective ranges from '*Best imaginable*' to '*OK*' reflect the ranges of the quartiles of the data used to generate and validate the adjective rating scale.

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Table 2. Sauro et al. SUS Curved Grading Scale (2016)

Grade	SUS score	Percentile range
A+	84.1 - 100	96 - 100
A	80.8 - 84.0	90 - 95
A-	78.9 - 80.7	85 - 89
B+	77.2 - 78.8	80 - 84
B	74.1 - 77.1	70 - 79
B-	72.6 - 74.0	65 - 69
C+	71.1 - 72.5	60 - 64
C	65.0–71.0	41 - 59
C-	62.7 - 64.9	35 - 40
D	51.7 - 62.6	15 - 34
F	0 - 51.6	0 - 14

Table 3. Adjective Rating Scale for SUS Scores (Bangor et al., 2008)

SUS Score Range	Adjective
85.59 - 100.00	Best imaginable
72.76 - 85.58	Excellent
52.02 - 72.75	Good
39.18 - 52.01	OK
25.01 - 39.17	Poor
0.00 - 25.00	Worst imaginable

Alternatively, benchmark scores can be calculated for each item in the SUS, as in the 2018 study by Lewis and Sauro. The overall SUS score is a broad evaluation of system usability, but each item in the SUS is targeted towards specific qualities of system usability. For example, item 2's target is system complexity whereas item 10's target is intuitiveness. In a case where there are specific qualities of the system's usability that need to be scrutinised, item-level SUS benchmarks are helpful. Simple linear regression equations where inputting a goal overall SUS value can calculate a corresponding item score. In other words, by using the goal overall SUS score, the target score for each item needed to achieve the goal overall SUS score can be calculated. The regression model is unaffected by the omission of one of the 10 items in the SUS as well (Lewis and Sauro, 2018).

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Table 4 lists the regression equations for each item in the SUS questionnaire. The table also shows the item scores needed to achieve a goal overall SUS score of 68 (50th percentile or average) and for a goal SUS of 80 (90th percentile), including lower and upper limits for a 95% confidence interval. For example, if the goal is to achieve a SUS score of 80, an item score of 4.19 would be necessary for item 7 about learnability. Alternatively, if the item score is known, it would be possible to calculate a corresponding SUS score. For example, if it is known that an item score of 4 was rated for item 9 for confidence, it could be calculated that the score of 4 corresponds to an overall SUS score of 74.4 ($SUS = (4) - 0.6992487 \; / 0.04435754 = 74.4$).

Table 4. Item-level SUS Benchmark Scores (Lewis & Sauro, 2018)

Regression [R^2]	Lower limit	Target for SUS = 68 (50th percentile)	Upper limit	Lower limit	Target for SUS = 80 (90th percentile)	Upper limit
SUS01 = 1.073927 + 0.034024(SUS) [34.5%]	3.30	≥ 3.39	3.47	3.69	≥ 3.80	3.90
SUS02 = 5.834913 - 0.04980485(SUS) [89.3%]	2.42	≤ 2.44	2.48	1.81	≤ 1.85	1.89
SUS03 = 0.4421485 + 0.04753406(SUS) [88.1%]	3.64	≥ 3.67	3.71	4.21	≥ 4.24	4.28
SUS04 = 3.766087 - 0.02816776(SUS) [51.7%]	1.80	≤ 1.85	1.90	1.45	≤ 1.51	1.57
SUS05 = 1.18663 + 0.03470129(SUS) [75.0%]	3.51	≥ 3.55	3.58	3.92	≥ 3.96	4.01
SUS06 = 4.589912 - 0.03519522(SUS) [73.9%]	2.16	≤ 2.20	2.23	1.73	≤ 1.77	1.82
SUS07 = 0.9706981 + 0.04027653(SUS) [84.6%]	3.68	≥ 3.71	3.74	4.15	≥ 4.19	4.23
SUS08 = 5.575382 - 0.04896754(SUS) [86.5%]	2.21	≤ 2.25	2.28	1.61	≤ 1.66	1.70
SUS09 = 0.6992487 + 0.04435754(SUS) [85.0%]	3.68	≥ 3.72	3.75	4.21	≥ 4.25	4.29
SUS10 = 4.603949 - 0.03692307(SUS) [67.6%]	2.05	≤ 2.09	2.14	1.59	≤ 1.64	1.71

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2.3.2 Eye-tracking

In testing the usability of a platform hosting spatial and archival data, eye-tracking technology can give great insight into user focus and attention while interacting with an interface. Eye-tracking for usability testing is a psychophysiological approach that assumes a connection between the eyes and the mind. Visual attention patterns (physiological) are seen to be a representation of mental attention patterns (psychological). Gaze fixations and saccades (quickly moving between two points) are the types of eye movements that are recorded by most modern eye trackers. Analysing the gaze of a user when confronted with visual stimuli can be used to not only support the assessment of interface usability but also the learning process (Wang et al., 2019). In the learning process, it is essential that available working memory capacity is not overloaded. Memory capacity can become overloaded when learners are confronted with instructional material that is laid out ineffectively. Through eye-tracking, the visual search can be mapped as a learner looks for relevant information amongst different sources (Jardodzka et al., 2017).

The data gathered from an eye-tracking study can be visualized and analysed in a variety of ways. In-context visualizations overlay a visualization of the analysis (e.g., attention/fixation heatmaps, gaze-path plots, etc) on an image of the stimulus. Although not-in-context visualizations are possible, adding a thumbnail image of the stimulus shown to participants as a background image for the visualizations makes understanding the result of the analysis easier. Graphical visualizations are also used in eye-tracking analysis. Such visualizations include line and bar charts, scatter plots and box plots. Analysis can be conducted for individuals or be aggregated to represent multiple individuals. Visualizing the eye movements of participants at the individual level is valuable in that the viewing behaviour of each individual can be identified in addition to any outliers or unique behaviours. Care should be taken when aggregating the eye-tracking data from all of the participants. Aggregated data can result in visual clutter. However, this can be resolved through averaging (Blascheck et al., 2014).

2.3.3 Combining Usability Testing Methods

Traditional usability testing techniques such as the SUS identify user satisfaction and interface effectiveness and efficiency. However, the SUS is more useful as a component in the interpretation of system usability moreso than as a sole indicator of usability. Traditional techniques and eye-tracking all have their advantages and disadvantages but can be used in tandem as complements to each other. Coupled with subjective usability assessments, iterative testing and success in completing tasks, the SUS can provide more valuable and in-depth insight into the usability of a platform (Kortum & Peres, 2014; Wang et al., 2019).

2.4 Usability Testing in Digital Humanities and Heritage Studies

The seamless flow of information starting from excavation to publication and archiving is the core of digital archaeology (Lock, 2003). However, there are not many usability studies conducted to test the usability of online archaeological tools. As an archive-intensive discipline of the digital humanities, the field of archaeology often utilizes online repositories as a common tool to access digitally stored

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information. Even in this regard, no detailed research has been conducted for the information needs and online tools used by archaeologists (Brandsen et al., 2021). When conducted, usability evaluations in archaeology are often applied to VR, digital museums and 3D content (Karoulis et al., 2006; Pescarin et al., 2014; Huurdeman & Piccoli 2020).

Fountain of the Lions is the name of the fountain and statues in the Nazaries Palace, which forms part of the Alhambra, a UNESCO world heritage site, located in Granada, Spain (Tromp et al., 2018). An interactive software program, named after the fountain and statues, was developed for viewing and manipulating 3D models of the historically and artistically famous site. The models can be viewed on a computer, a touchscreen device or in a VR environment, allowing users to manipulate the viewing angle. Models have a very defined texture, allowing users to see the Arabic inscriptions on the fountain. Users can also select a feature in the models and read extra information about it. The site can be viewed as it appeared before and after its 2013 restoration through this application, to further user understanding of the preservation and restoration process. Artists, archaeologists, historians and general visitors of the site were identified as target users. With the expected differences in user experience, knowledge and skill amongst the target users, three personas were created for the usability evaluation. The personas consisted of two positive (a professor and a computer-literate child) and one negative (a computer-illiterate retiree). The personas were used to help identify the particular needs of the persona and the hypothetical ways in which they would interact with the application. A cognitive walkthrough was performed whereby a series of tasks in a 2D and 3D environment was executed through the hypothetical lens of the persona and rated. The rating answered the questions in Table 5 on a scale of one through five [1 = No, never; 2 = No; 3 = Maybe sometimes; 4 = Yes; 5 = Yes, always].

Table 5.Cognitive Walkthrough Questions for 2D and 3D Tasks (Tromp et al., 2018)

2D Task Analysis	3D Task Analysis
Will the user realistically be trying to perform this action?	Can the user form or remember the task goal?
Is the control for the action visible	Can the user determine what to do?
	Can the user view and locate the objects that are necessary to carry out the task?
Once the user finds the correct action in the interface, will they know it is the right one for the effect they are trying to produce?	Can the user approach and orient towards the objects to carry out the task?
	Can the user decide what action to take and how to take it?
Is the feedback appropriate?	Can the user carry out the manipulation or action easily?
	Is the consequence of the user's action visible and understandable?
Upon task completion, is there an obvious next action for the user to perform?	Is it clear to the user what the next correct/needed cation could be?
	Upon task completion, is there an obvious next action for the user to perform?

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Located at the Finnish-Russian border, the World War II Salla graveyard is a cultural heritage site that is difficult to visit, due to a lengthy application process to acquire a permit to access the border zone (Häkkilä et al., 2019). This study used virtual reality as a solution to make visiting the cultural heritage site possible. A virtual graveyard was developed, allowing users to navigate through the graveyard using a head-mounted display. The Oculus Rift CV1 was used as the head-mounted display hardware for the prototype. The project was developed using Unity3D and 3D models were built in Blender using photographs taken by visitors. Textures were created from a high poly model and applied to a low poly model. The virtual graveyard created an immersive atmosphere visually, by allowing changes to daylight and weather conditions and audibly through spatial audio. A temporal element was also added whereby tree growth and the number of gravestones would change over time. Although the intention was to create the virtual graveyard to be as accurate to the real world as possible, there were mixed responses from the participants when they tested the prototype using a head-mounted display. The spatial audio received the most mixed responses, with some feeling that the audio was annoying while others felt that it added to the atmosphere. Some also felt that the spatial audio was not realistic enough, lacking sounds of wind blowing for example. Participants also struggled with navigation. The walking navigation was found to be too slow, however, speeding it up caused nausea. The head-bobbing movement involved in the walking navigation also caused nausea. Alternatively, the 'teleportation' navigation helped with nausea but was difficult to accurately control. Each testing session for the prototype took about an hour, although half of the participants had experience with VR systems. The complexity of VR systems and their accessibility to a broader audience was questioned due to the difficulty that participants experienced especially with comfortable and accurate navigation through the virtual graveyard.

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Chapter 3: Design and Development of 3D Visualizations of Seoke

This chapter introduces the process used to develop the 3D models that altogether made up the Seoke 3D scene. The 3D models were built as one of the contents to be embedded into the exploratory environment to facilitate the conceptualization of Seoke, considering its physical inaccessibility. The outline section introduces the specific criteria that the final models and scene should meet in addition to the data, software, code and design choices utilised for building the models and scene. The results and evaluation section examines the strengths and limitations of the models and scene and how well they met the requirements in addition to discussing issues that were identified during the process that are important to note. Lastly, statements about the models that advise the later chapters and further work are addressed in the summary and discussion section.

3.1 Outline

3.1.1 Motivation

The most visually apparent remains of Seoke are the stone walls (Section 1.4). To an individual who is not a specialist or is not thoroughly knowledgeable about pre-colonial southern African settlements, seeing the stone walls through traditional mediums such as photographs or 2D maps will not be enough to conceptualise Seoke in space or its previously inhabited state (Yin 2010). Photographs will provide a very zoomed-in and narrow view of the site, in a manner that exempts the spatial context and arrangement of other related objects in the site. As seen in Figure 3, the photograph of the stone wall segment, while looking realistic, does not provide any insight into its location relative to other wall segments. Alternatively, 2D maps (Figure 4) not only remove the viewer completely from the scene and provide only a bird's-eye overview of objects but also represent them using symbols, thus transforming the real world in abstractions (Seipel & Carvalho, 2012).

Figure 3. A Stone Wall Segment at Seoke, Photographed by Brenda Maina, 2020

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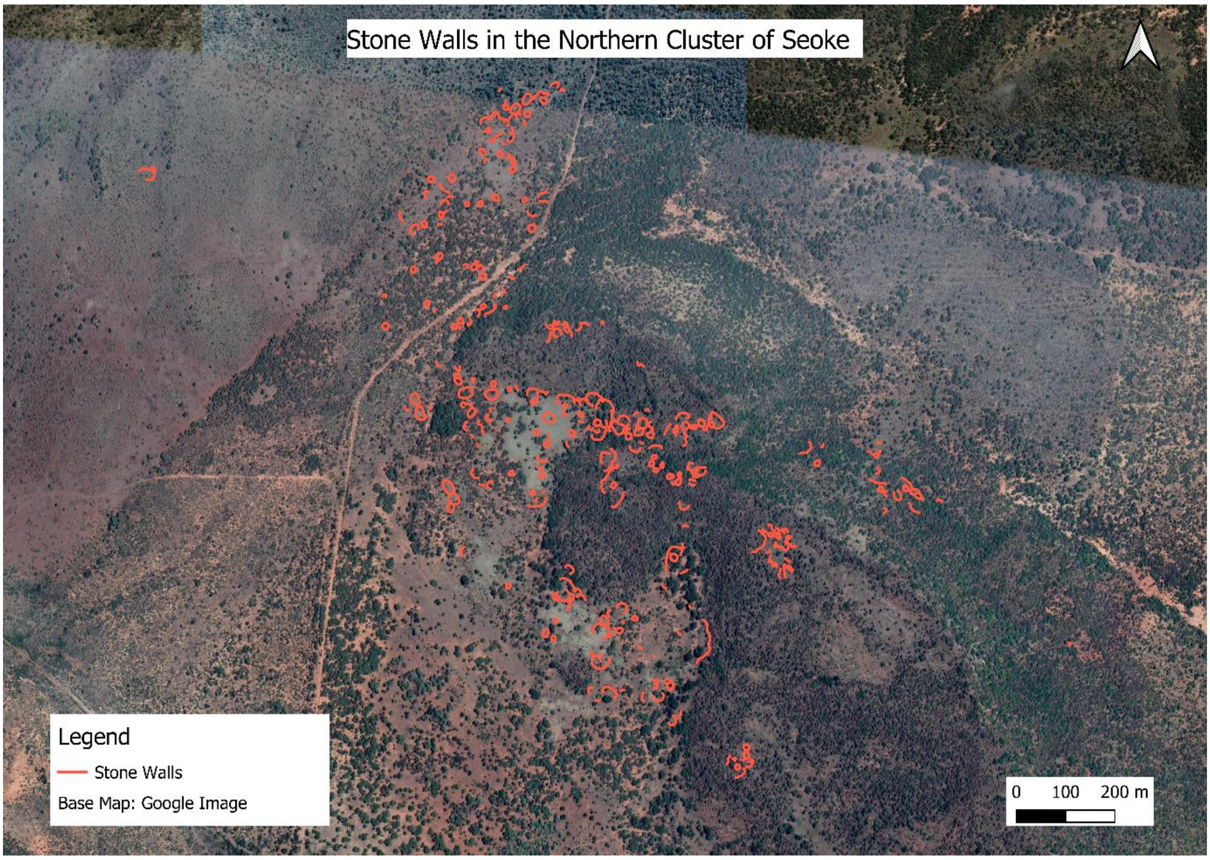

Figure 4. A Map of the Northern Clusters of Stone Walls in Seoke

**Stone wall data was created by Stefania Merlo*

A 3D component will fill the gaps left by photographs and 2D maps as visual mediums for learning and in conjunction with photographs and 2D maps, create a more comprehensive exploratory environment. By representing the geospatial data for Seoke in 3D and spatially organising models into a 3D scene, viewers can get more insight into the spatial relationships between objects while still experiencing a degree of realism. As such, the bird's-eye objectivity available in 2D maps and the realism available in photographs can be simultaneously achieved. This is especially necessary in light of the site's physical inaccessibility. The geospatial data for the site, encompassing the stone walls and other material remains, are better suited to be visualized based on their 3-dimensional attributes. As niche objects (archaeological artefacts that may be unfamiliar to a lay person - i.e., middens, grain bins, grinding stones, etc.), described using jargon, visualizing the objects based on their physical attributes makes information about the objects more accessible and attractive to a wider audience. Moreover, as niche objects, representing objects as 3D models is also useful for object recognition and information retention (Loschky et al., 2010).

3.1.2 Design Characteristics

The design characteristics that the 3D Seoke visualization should have are as follows:

i) Spatially organized known and informed spatial data: Firstly, visualize the known spatial information about Seoke to illustrate the textual information. While the archaeological material remains discovered at the site will have locational information attached to them (i.e, stone walls,

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middens, etc.), other elements (i.e., cultivated fields, vegetation, etc.) can only be inferred. Some objects will have to be placed in the scene to creating a more complete image of the site even though their existence is based on textual evidence and not physical evidence (material remains). Objects that do not have a known location should be built within the scene using informed assumptions.

ii) Portrayal of the physical environment: The overall appearance of the scene should portray an image that is fitting to the place and time in which the scene is set. This should be achieved through the physical environment recreated by vegetation models, sky panorama, incident sunlight and the material culture through the integration of archaeological and ethnographic expert knowledge that has been gathered in specialized studies and archival research.

iii) Realism: The models are built using spatial data grounded on real archaeological data collected at the site. Models should be portrayed with appropriate textures, dimensions and scales to portray functional realism. As the models will be organised together to create a 3D scene, objects must be of the appropriate scale relative to each other. It is especially important to accurately capture objects that are not mainstream or well known.

3.1.3 Software

QGIS is a free and open-source desktop geographic information system (GIS). The application can be used for the viewing, editing and analysis of geospatial data (QGIS, 2021). Version 3.10.6 was used to clean and manipulate the shapefiles in preparation for 3D modelling in CityEngine. CityEngine is a software developed by Esri to support the 3D mass modelling of urban environments. Other 3D modelling software were evaluated, namely Blender and Unity. However, due to data format compatibility, hosting costs and the user learning curve, CityEngine was ultimately selected. CityEngine can support georeferenced spatial data formats such as shapefiles and GeoTIFFs. This would support the building of 3D models based on the digitised footprints of the stone walls found in Seoke. Additionally, 3D scenes can easily be hosted on ArcGIS Online and distributed online. For the development of the models, Version 2019.1 of CityEngine was used. Models in CityEngine can be built using Computer Generated Architecture (CGA), which is a software-specific coding language used to write the ‘rule file’ of structures. Although there are other methods for building models in CityEngine, writing rule files is the best method for mass modelling, as the rule file can be assigned to multiple shapes at a time. CityEngine comes equipped with comprehensive tutorials to help a first-time user learn how to write CGA and to fully maximise the capabilities of the software.

3.1.4 Data and Tools

The spatial data used in building the models were created by Stefania Merlo, through digitization using aerial imagery and on-site survey using a hand-held GPS (Figure 2; Figure 4). The list of 2D spatial data used to create the 3D models can be seen in Table 6. Furthermore, some objects were represented by models sourced from external providers. The cattle models were sourced from Creazilla and Sketchfab and the cornfields were sourced from Free3D. The 3D model of the grinding stone is one of a grinding stone found at the site and was created by Anton Coetzee. The externally sourced models were imported into CityEngine and inserted into the scene based on the georeferenced shapefiles for the objects’ locations.

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Table 6. List of Spatial Data Used

Spatial Data	Author	2D Format	Date	Description
Seoke central	Stefania Merlo	Shapefile – vector line	Received: 19-05-2020	Digitized line vectors for the central cluster of stone walls in Seoke.
Seoke North	Stefania Merlo	Shapefile – vector line	Received: 19-05-2020	Digitized line vectors for the northern cluster of stone walls in Seoke.
Seoke South	Stefania Merlo	Shapefile – vector line	Received: 19-05-2020	Digitized line vectors for the southern cluster of stone walls in Seoke.
Seoke Google	Stefania Merlo	Shapefile – vector line	Received: 19-05-2020	Line vectors for the stone walls in Seoke, digitized using Google aerial images.
NC Survey	Stefania Merlo	Shapefile – vector point	Received: 10-2019	Point vectors of material findings, found in the northern cluster of Seoke through an on-site survey. Material findings include bone, grain bins, grinding stones, lithic fragments, platforms, potsherds, quern stones, sliding doors, spears and spearheads.
NC Middens	Stefania Merlo	Shapefile – vector polygon	Received: 06-10-2020	Polygon vectors of middens found in the northern cluster of Seoke.
Kraal	Stefania Merlo	Shapefile – vector polygon	Received: 06-10-2020	Polygon vector of a large cattle enclosure in the northern cluster of Seoke based on material evidence.
NC Kraal	Brenda Maina	Shapefile- vector polygons	Created: 09-10-2020	Polygon vectors of assumed locations of cattle enclosures in the northern cluster of Seoke, based on expert advice and the shape and size of stone enclosures.
Dwellings	Brenda Maina	Shapefile – vector polygon	Created: 09-10-2020	Polygon vectors of assumed locations of dwellings in the northern cluster of Seoke, based on expert advice and the shape and size of stone enclosures.

3.1.5 Scene Elements

The scene elements worked in tandem to depict Seoke akin to how it appeared when it was inhabited, based on the known and assumed locations of the found or theorised material remains of the site. The availability of spatial data determined which objects were modelled and the models were designed based on reference photographs and drawings as well as expert advice. Of the objects for which spatial data was available, the stone walls, middens, grain bins and grinding stones were selected to be modelled, the latter three chosen due to their dimensions that allowed for visual impact in the scene. Other material findings, namely bone, lithic fragments, platforms, potsherds, quern stones, sliding doors, spears and spearheads, were not modelled, mostly as these objects would appear too small relative to the scale of the scene or not enough information was available about the objects.

Scene elements with no known location - namely dwellings, cattle kraals, crop field and vegetation - were also added to the scene. Dwellings were modelled as they are critical in depicting an inhabited space. The locations of dwellings in the 3D scene were based on informed assumptions and expert advice. Cattle were a very important status symbol to the Bangwaketse and it is known that there

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were many cattle in Seoke. As such, they were also added to the scene. The objects were modelled as they would have appeared at the time that Seoke was inhabited.

3.2.3.1 Stone Walls

The digitised stone wall data was initially received as line vector data. It was first loaded into QGIS where it was buffered at 0.25m to create a polygon footprint with a width of 0.5m for the walls. These dimensions were set based on the advice of Stefania Merlo, who had conducted surveys at the site and measured the width and height of several walls. The footprints were then smoothed to remove some of their angularity after which they were loaded into CityEngine. The rule file for the walls first determines the area of the footprint. Because not all of the walls had height attributes, wall height was set to be determined by footprint area, again, based on the advice of experts of the site. Walls with a footprint area of less than $10m^2$ were set to have a height of between 0.1m to 0.3m. Walls with a bigger footprint area were set to have a height of between 0.7m to 1m. With the walls extruded, a texture was projected onto the model, with different projection dimensions for the sides and the top of the walls to maximise visual realism. A bump map was also added to further enhance the illusion of the texture being raised (Annex 2).

Figure 5. Stone Wall Models Compared to a Photograph of Stone Walls in Seoke. Photograph by Brenda Maina, 2020

3.2.3.2 Dwellings

The dwellings are a recreation of what living spaces may have looked like within the stone enclosures. Several drawings and photographs (Figure 6; Figure 7) were referenced in addition to the expert advice of Stefania Merlo, Amanda Esterhuysten and Fred Morton to develop accurate models of the dwellings. The footprints of the dwellings were created in QGIS within the Stone Walls that were identified to most likely have been an enclosure for dwellings. This was based on the enclosure size, the width of the enclosure entrance and the presence of middens for some. Often, there would be multiple dwellings within one enclosure to accommodate for the privacy of each woman married to the same man. The dwelling footprints have a radius of 4.5m, based on knowledge from literature and traditional Tswana dwellings (Larsson & Larsson, 1984).

The rule file (Annex 3) for the main structure extrudes each dwelling to a height of 3m. A texture was projected onto the dwellings to replicate a mud wall. The door is made up of an arched opening made in the walls. Dwellings at the time did not have windows, thus, they were not included in the model. The thatched roof was extruded at a slight height of 5cm to add dimension to the projected thatch texture. A separate rule file (Annex 4) was written to create the veranda and wooden beams that were

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used to support the weight of the roof. The veranda has a width of 80cm and acts as a support for anchoring the wooden support beams. The beams were made up of extruded cylindrical shapes and each beam was assigned a random wooden texture to reduce uniformity.

Figure 6. Reference Illustration of Tswana Veranda Dwellings, Illustrated by John Campbell, 1820

Available at: www.kadishwene.com

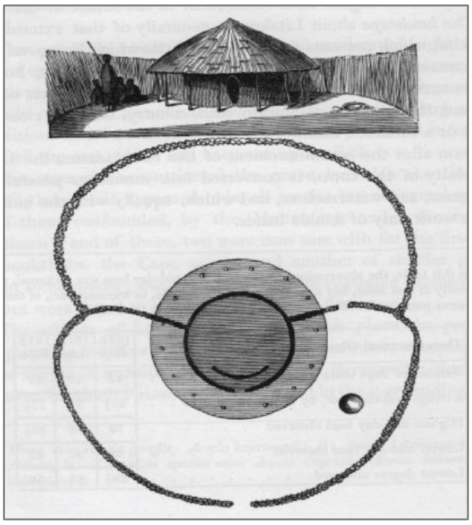

Figure 7. Reference Illustration of a Tswana Dwelling by William Burchells, 1812

Figure 8. Dwelling Model in the Seoke Scene

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3.2.3.3 Vegetation

The study area is currently quite densely vegetated, with tall grass in the lowlands and tree cover up on the hills. However, when the area was inhabited, it was far less densely vegetated as the vegetation was cleared away for building the settlement and for cultivation. As such, the scene shows low grass with several trees and bushes scattered around. To achieve this, the preloaded vegetation models that come with the CityEngine software were used (Annex 5). The CityEngine software comes preloaded with 127 plant species, available in the Esri library. The models available in the library were examined against the common tree species in the South-east districts of Botswana (Setshogo & Fenter, 2003), where Seoke is located. The species in the library consist mainly of species indigenous to the Americas and Europe with a few Asian and African species. The load time for the CityEngine models is much faster than that of vegetation models from external providers. As such, CityEngine vegetation models were used in the scene, although they are not accurate representations of the species found in the study area. The vegetation chosen for the scene (Table 7) were selected based on their aesthetics, with characteristics such as colour, size and dryness, evaluated against photographs of the site (Figure 9).

Table 7. List of Vegetation Models from the ESRI Library that were Used in the Seoke 3D Scene

Trees	Bushes
Apricot*	Alder Buckthorn
Desert Willow*	Boxwood
Umbrella Acacia*	Common Hawthorn
Osage Orange	Flannelbush
American Pepper	Hedgehog Agave
Palo Verde	Shadbush
Western Soapberry	Witch Hazel
	Mexican Buckeye
	Northern Bilberry
	Southern Wax Myrtle

*Species found in southeastern Botswana

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Figure 9. Vegetation at the site Compared to Vegetation in the 3D Scene. Vegetation at the site Photographed by Brenda Maina, 2020

The Bangwaketse also grew crops such as sorghum and millet. The crop fields in the scene were created using a model and texture sourced from Free3D (available at: https://free3d.com/3d-model/-corn-field-v1--790634.html), an external online provider. There is no clear evidence available as to where the crops were specifically grown in Seoke, as such, creative freedom was used to select the location of the crop fields in the 3D scene. The polygons for the crop fields were created in CityEngine, and models were inserted onto the polygons at even intervals to create the image of rows of plants (Figure 10).

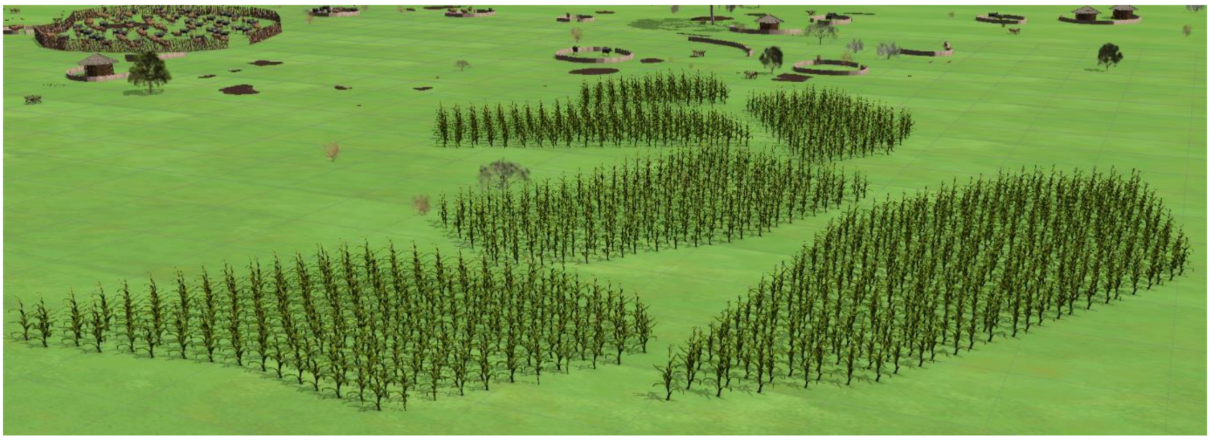

Figure 10. Millet Models in the Seoke Scene

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3.2.3.4 Cattle and Kraals

Cattle were seen as important assets by the Bangwaketse and represented wealth and power. The Bangwaketse, like many other Tswana speaking groups at the time, often raided neighbouring groups for their cattle. As such, it is estimated that there would have been hundreds of cattle in Seoke. Cattle were kept in cattle kraals (cattle pens), which were often stone enclosures similar to those for dwellings except they had narrower entrances. Other cattle were kept in enclosures made with thorn bush and wood. Botswana cattle have a well-known and distinct appearance. The Sanga cattle of southern Africa have horns and necks that make them visually different to European breeds of cattle (Figure 11). Due to their distinctive characteristics, it was important to have cattle in the scene that resemble Tswana cattle. However, the 3D cattle models that are available were modelled after European breeds. Due to this limitation, the cattle models chosen for the scene were selected based on other characteristics such as colouring and size (Figure 12).

The models and texture were sourced from Creazilla (available at: https://creazilla.com/nodes/3177-cow-3d-model) and by GSCreations on Sketchfab (available at: https://sketchfab.com/3d-models/cow-skin-f79f2bc987f94c9ead02a36844e7c48b) and were distributed within the kraals using the code in Annex 8.

Figure 11. Sanga Bull

Available at: https://www.thecattlesite.com/breeds/contents/tulibull.jpg

The models for the stone enclosures were created using the same code as what was used for all of the stone walls in the general scene (Annex 2). The model for the wooden kraal was created by extruding cylinders at even intervals along the outline of a polygon shape. Each cylinder was then tilted at random angles and also shifted a random distance to recreate the irregular intertwined branches. The cylinders were also assigned a random wooden texture (Annex 7). Using thornbush models to create the wooden kraal caused lagging issues, as such the simplified cylindrical poles were used as a work-around (Figure 12).

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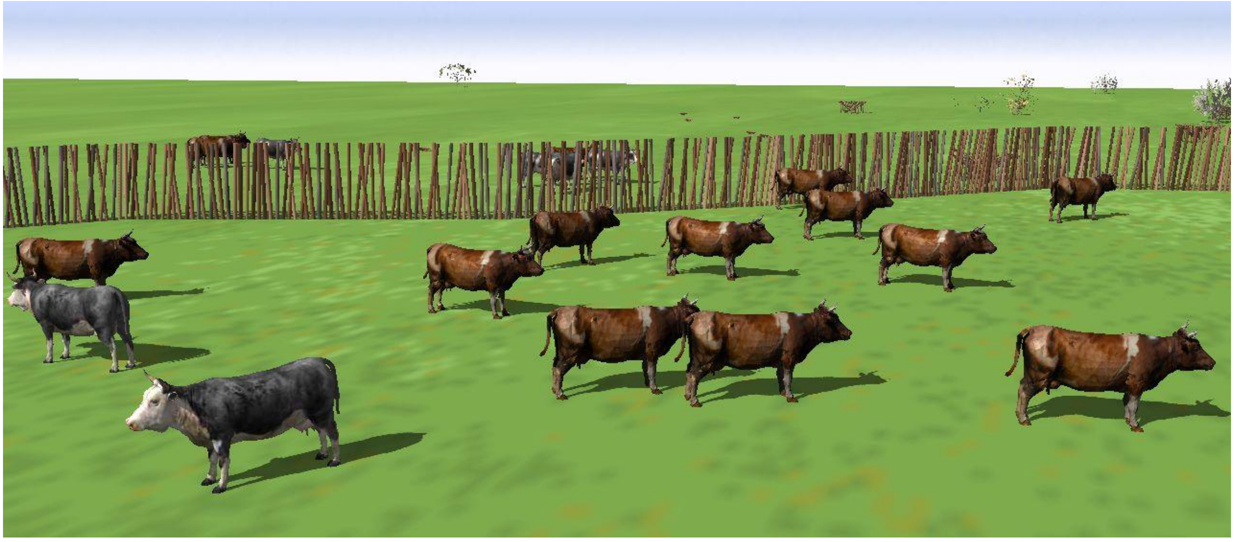

Figure 12. Cattle Models in the Seoke Scene within the Wooden Cattle Enclosure

3.2.3.5 Middens

Middens were rubbish pits that could be located either behind the back portion of a dwelling enclosure or in the centre of a cluster of dwellings. They were covered with dirt after they were filled, and these extrusions are what remain to this day. The models of the middens were created by creating extrusions that peaked at the centre of the midden polygon. The random heights were assigned for the peaks of the middens (Figure 13). Lastly, a dirt texture was added to the midden models (Annex 9).

Figure 13. Midden Model in Seoke Scene

3.2.3.6 Grain Bins

Grain bins were wooden structures used to store grain and produce. The structure consists of a cone-like shape that is made of intertwined branches that work as the container and beams that work like stilts to keep the container off of the ground (Figure 14). A small, circular arrangement of stones inserted in the ground would have served as the base for the grain bin cone and it is the trace of such structure that can be found today. The spatial data for the grain bins, indicating the centre location of the small wooden structure, consisted originally of point vectors. These were converted into polygons using a buffer operation to be more compatible with CityEngine. The model of the grain bin was created in two parts. The container was created using a 6-sided cone-like shape, where each face of the shape was made up of cylinders spaced out over even intervals. The cylinders were assigned random wooden textures (Annex 10). The beams were created by extruding cylinders along the outline of the grain bin polygon at even intervals. On top of the support beams, a ring of intertwined branches was added. The cylinders were also assigned random wooden textures (Annex 11).

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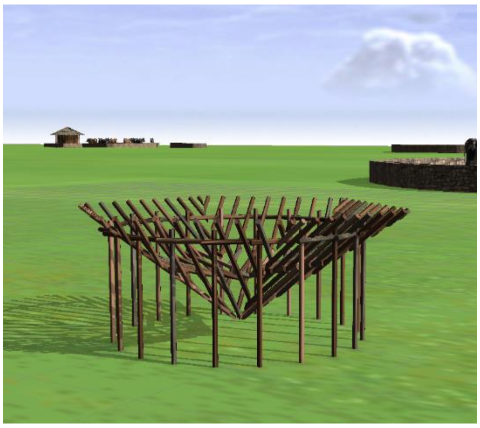

Figure 14. 3D Model of a Grain Bin in the Seoke Scene

3.2.3.7 Grinding Stones

Grinding stones are stones with concave surfaces that were used as a base to crush ingredients such as cereal seeds, tobacco, or ochre. The crushing was done using an ellipsoidal stone, known archaeologically as a quern stone (Figure 15). When found at the site, they are identified by their characteristic shapes, but also from samples taken of traces on their surfaces that are then identified in a lab. The model used for the scene was a 3D model made by Anton Coetzee and was made from photographs of a grinding stone that was found in Seoke (Annex 12).

Figure 15. Model of a Grinding Stone and Quern Stone in the Seoke Scene, Created by Anton Coetzee, 2020

3.2 Results and Evaluation

The results section presents the model and scene development outcomes against the design characteristics that were previously outlined in Section 3.2.3.

3.2.1 Organization of Known and Informed Spatial Data into a 3D Scene

After the models of the various objects were built, they were organized according to the relevant geospatial data. In doing so, scenes were created whereby objects were spatially organised to create a visually communicative presentation of the known and informed locational information for the site.

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In the process of organizing the 3D spatial objects into a scene, building a single 3D scene for the entirety of Seoke became difficult. The spatial data sets for Seoke consist of several hundred objects, with the stone wall dataset alone consisting of over 1000 objects. Building one scene using all of the objects in the datasets available raised concerns regarding load time during distribution. In distributing the 3D scene online, loading errors occurred during viewing, due to the large size of files for a 3D scene for the entirety of Seoke. Therefore, a smaller segment of the site was selected from which a 3D scene was created. For this, the Northern cluster of stone walls was selected.

The Northern cluster of Seoke was selected as it is an area of the site for which excavations and surveys have produced the most variety of spatial data. Other areas in the site that have not been excavated or surveyed are limited to larger and more visually apparent archaeological remains such as stone enclosures and middens. The wider variety of spatial data available for the Northern cluster also provides for more data points from which inferences can be made for the locations of spatial objects with no known location, such as dwellings, cattle and crops. Altogether, 3D models of stone enclosures (for living spaces and cattle), dwellings, griding stones, grain bins, middens, vegetation, crop fields, cattle and a cattle kraal were organised into a scene to depict the Northern cluster of Seoke. Building a scene with various objects created an environment that seems inhabited. Although the scene is not a whole duplicate of what Seoke looked like at the time, it creates a simplified visual backdrop for learning about Seoke.

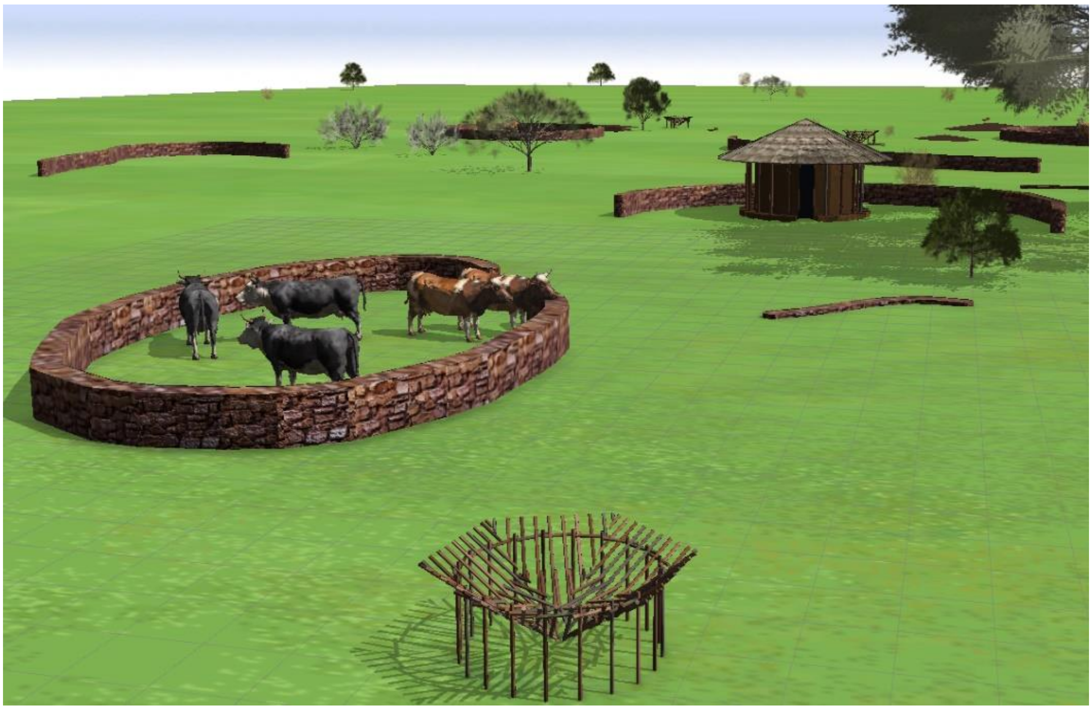

Figure 16. Seoke 3D scene

3.2.2 Portrayal of the Physical Environment

The vegetation models are important for adding to the realism and as they are important cues for the place and time that Seoke existed in. Seoke at the time was cleared of most of the natural vegetation, remaining with short grass and a few trees and bushes. The selection of vegetation species and the density of distribution are important nuances that can quite dramatically change the setting. As seen in Figure 18, in an earlier version of the Seoke scene, an inappropriate mix of vegetation species were

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chosen and was distributed over the scene with an overly high distribution density. The combination of trees that were too tall and close together creates a setting that does not look like southeastern Botswana and will impact the immersiveness of the scene. A later version of the Seoke scene (Figure 17) had more bushes with a few trees with the vegetation being more widely spread apart, which was a better recreation of the setting.

Figure 18. Early Version of the Seoke Scene with Vegetation

Figure 17. Later Version of Seoke Scene with Vegetation

Adding to the physical environment of Seoke, the site lies on hilly terrain. It would, therefore, have been ideal to integrate this topographic information through the landscape. However, it was not possible to build the 3D scene onto a terrain in CityEngine due to limitations in the software. When a terrain is created in CityEngine, the other objects in the scene need to be fitted onto the terrain. This is easy to achieve when CityEngine is used to build a scene of a modern urban city. Most cities are built on relatively gentle slopes, and in cases when a building is built on a steep slope, often the foundation of the building is built into the slope to create an even foundation. In CityEngine, this functionality is seamlessly supported for Block objects, which are blocks of buildings that are

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surrounded by street networks. The relative size and surface area of buildings in modern urban cities also make it easier for the software to align them onto a terrain. The larger surface area of modern buildings means that there are more tangent points with the terrain, making alignment easier. The objects in the Seoke scene are Shape objects, not Block objects and as such, were difficult to align to a terrain. Additionally, objects would 'float' above the terrain and the small dimensions of objects would not allow for seamless alignment for steep changes in terrain due to fewer available tangent points.

3.2.3 Realism

The 3D models and consequent 3D scenes were intended to achieve functional realism, whereby the same visual information is provided by the scene, as what exists in the real world (Hagen, 1968; Ferwerda, 2003). The 'real world' against which the Seoke visualization is referenced, is a combination of data for what is physically present and intact at the site, data of material findings and evidence and data that can be inferred from the two previously mentioned datasets. The combination of these datasets creates a geospatial 'real-world' of what is currently known of an inhabited Seoke in the 18th century. Within this premise, the 3D models and consequent 3D scenes are intended to provide reliable visual information about the location and organisation of these objects. As discussed in section 3.3.1, functional realism must also portray the scale, dimensions, materials and texture of objects, to support the task of learning, in particular.

Objects were built to scale in relation to each other. As the spatial data for the objects in the scene were spatially referenced, the objects were built within this reference frame. For 3D objects that were built in CityEngine, the shapefile footprints were used as the foundational shape upon which the models were built. The stone enclosures were randomly assigned heights within a range, however, the ranges were based on findings from on-site surveys. Imported 3D objects, namely the cattle, sorghum, grain bins and grinding stones were carefully sized, by referencing known average dimensions for the objects.

The dimensions of some objects were dictated by the functionalities of the software. CityEngine was developed primarily to recreate large urban cities in the developed world, characterised by high-rise buildings, intricate stone and concrete facades, glass panes and precise geometry and networks. Modelling Seoke required modelling a settlement that is much smaller in scale in comparison to modern urban cities, with structures made from natural materials and imprecise shapes with more organic networks. As such, the models are built 'too clean'. Objects with organic, irregular and rounded shapes in the real world were modelled using simplified geometric and angular shapes. This is particularly evident in the stone wall models. The models of the walls were extruded with flat planes (Figure 19), although the stone walls are more irregular and organic in shape.

Instead, the materials projected onto the models provide visual cues as to the nature of the objects. Materials such as stone for the enclosures and grinding stones, wood for support beams and grain bins, thatch for roofs and earth for dwelling walls worked to portray organicness in the models. In combination, the textures applied to the models helped to offset the geometric dimensionality of the objects by creating an appearance of unevenness and irregularity, using shadows. Appropriately assigning materials and textures greatly affected the overall image of models. This is evident in the early iterations of the dwelling models. Dwellings in Seoke had mud walls, which in reality would

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visually appear softer and irregularly textured. Finding the right combination of the texture image, projection dimensions and shadows to visually replicate the appearance of a mud wall was a process of trial and error. Due to design choices, earlier versions of the dwelling models appeared hard, dense and cement-like, which further emphasised a harsh geometry in the models that is an inaccurate representation of the dwellings that were in Seoke (Figure 20).

Figure 19. Stone Wall Models in the Seoke Scene

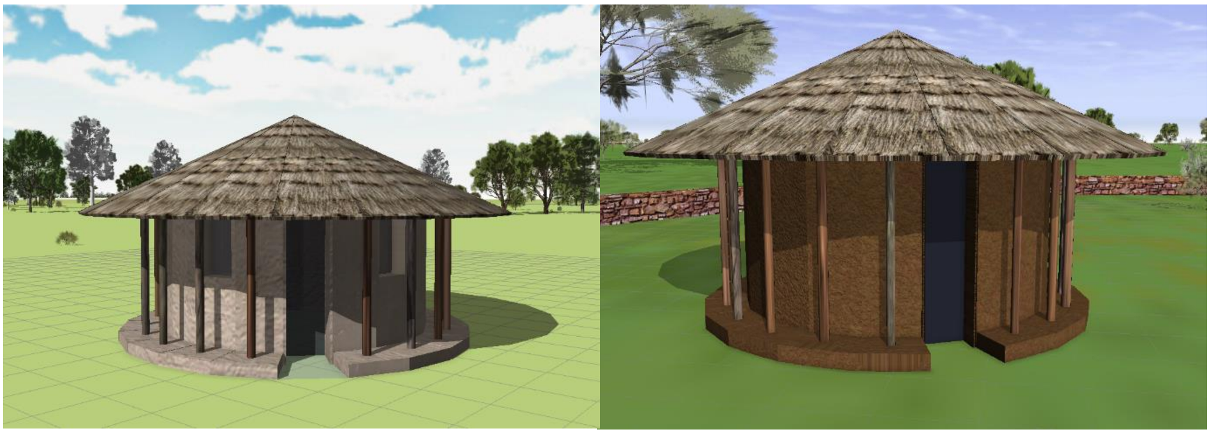

Figure 20. Early Version (left) and Later Version (right) of Dwelling Models

3.3 Summary and Discussion

The resulting scene conceptualizes Seoke in space in a way that is not possible through static drawings, photographs or 2D maps. The scene provides insight into the spatial arrangement and relative scale of different features and objects. The visualization of the geospatial data of Seoke in 3D was an appropriate approach when considering the 3-dimensional attributes of the data. Visualizing this information in 3D with functional realism more authentically represent the nuances and details of the site more so than a 2D abstraction of the data could have. The models provide a visual reference for objects that are not well known or mainstream, through the visual cues of their materials, dimensions and construction. Examples of the more unfamiliar objects in the Seoke scene include grain bins, middens and grinding stones. Without prior experience with these objects, it would be difficult to envision the appearance, scale or materials of these objects with just a textual description. The design

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choices for the physical environment within which these unfamiliar objects are arranged such as the vegetation, sky panorama, incident light and even livestock, also enhanced the communication of the nuances and details of the site.

However, the models should not be the only visual source of information given to viewers about Seoke. It is important in this case for the 3D models to be presented to viewers in conjunction with available archival materials such as drawings and photographs. Archaeological information is subject to differences in interpretation, changes in perception and changes in hypotheses that occur over time. Furthermore, the Seoke scene is merely a visual representation of the spatial data available for the site and is limited by the information and knowledge that was available at the time of its development. Although 3D models can portray the extent of Seoke in space, drawings and photographs add to a richer conceptualization of the site. Also, the models are not exact replicas of the objects that existed in Seoke especially as they were not built with hyperrealism or photorealism. CityEngine, the software used to build the models and scene, is catered to the modelling of modern cityscapes, and as such experienced limitations in modelling a pre-colonial settlement. The models built were characteristically too geometric and clean.

3D modelling has been found to cause cognitive overload; a mental burden caused when an individual is faced with processing a task that exceeds their mental abilities (American Psychological Association, 2020). Cognitive overload has been found to occur from the manipulation of dynamic 3D models, immersive 3D games and hypermedia 3D learning environments. This is especially the case for learners with a low spatial ability (Berney et al., 2015; Gerjets & Scheiter 2003; Paas et al. 2003; Huk, 2016). Even with the educational potential of the developed 3D models and the knowledge that can be gained from them, how they are presented to learners is a crucial variable. The intended users of the story map and the target audience for the study are expected to be a diverse group with unknown spatial capacity (see Chapter 4). Considering this, the presentation of 3D models in the story map must keep any potential cognitive overload to a minimum. The 3D contents must work in harmony with the other media in the story map. Learners should not have to rely on the 3D content for their understanding; processing how to view and understand the 3D content should not overwhelm the mental abilities of the learner.

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Chapter 4: Utilizing a Story Map as a Digital Exploratory Environment

This chapter discusses what story maps are, why the exploratory environment was presented as a story map and how the story map was made. The overview section introduces the intended user and design characteristics of the story map. The tools, data and media used to create the story map in addition to the links to objects in the archive are explained in the development section. The evaluation section presents the outline of the narrative and the design choices involved in the layout of the various educational materials. Lastly, the summary section elaborates on the story map as an educational tool that is equipped to facilitate the learning process of readers.

4.1 Overview

Story mapping is the use of a web application that integrates textual information with other media, mostly geospatial information presented in 2D maps but also including images, videos, and 3D visualizations. The textual information facilitates a storytelling approach for disseminating information that attaches character and narratives to the media in a way that makes learning more accessible (Berendsen et al., 2018). As a product, the story map was developed as an educational tool that presents niche and discipline-specific information about a pre-colonial African settlement in a simplified, concise manner for those who are not specialists or are not thoroughly knowledgeable about pre-colonial southern African history. The presentation of new or complex information can be executed in a manner that makes its assimilation more natural when characters and plots are attached to it (Berendsen et al., 2018), such as what is possible with story maps. In this regard, the Bangwaketse and their inhabitancy of Seoke respectively, fit the previously mentioned roles.

4.1.1 Intended Users

As an educational platform, the intended users of this story map are secondary school and university students. University students attending a Botswana or South African university were targeted in particular, considering participation for usability testing. Encompassing undergraduate to postgraduate students, the target user would, on average, be in their early twenties. The university students are not experts about pre-colonial southern African history; however, they may be enrolled in courses that are somewhat related to the story map, provide context to the information presented or how that information is presented. Moreover, the target user is expected to have reading and comprehension skills in English in addition to internet access and computer skills, mainly regarding using a computer mouse.

4.1.2 Design Characteristics

A story map was selected as the medium through which the exploratory environment is presented for two main reasons. Firstly, a story map can be used to disseminate complex information in a format that is more natural to a learner. As the target user may not reap major rewards in their academic or work environment from learning about Seoke, their interest in Seoke may be momentary and situational. As they may have limited internal motivation to learn about the site, it is important to

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generate motivation and interest externally through engaging information that is laid out effectively. Secondly, a story map can be used to naturally integrate various forms of media that support the main textual information of the story map. The target user may not be willing to invest a lot of time reading long and complex information about a subject they are not familiar with. Making use of various forms of educational media can make the learning process more visually and auditorily engaging.

Although part of the initial proposal of the study, the design characteristics of the story map was collectively discussed and agreed upon with the collaborators of the *Metsemegologolo* project (Section 1.1; Annex 1) over multiple workshops, virtual meetings, conversations and email correspondences. After reading various sources on Africanist approaches to urbanism, Tswana mega-towns and the Bangwaketse in particular, narratives were constructed. These narratives were presented to the *Metsemegologolo* team, comprised of several lecturers and teachers. Revisions and refinements were made until the themes of the narrative were approved, resulting in design characteristics for the story map which are as follows:

i) Concise Structure: To support learning, the narrative of the story map must have a clear and concise structure with an introduction, a body and a conclusion. There must be a clear introduction to characters, physical environment and milieu.

ii) Variety of Media: Secondly, the story map must have a curation of various forms of media including 2D maps, images, video and 3D visualizations that support the narrative and a multi-faceted discussion of a pre-colonial southern African past. Users should be presented with the various mediums of spatial and archival information available for the site.

iii) Link to the Archive: Lastly, a curation of materials from the *Metsemegologolo* digital archaeological archive (Section 1.1) must be integrated into the story map. The curation of materials must support the narrative and the discussion of the pre-colonial southern African past in addition to providing archaeological, archival and academic access to Seoke.

4.2 Development

4.2.1 Applications

The story map was created using ArcGIS StoryMap, an online application by Esri. The application is available to use for ArcGIS Online users. Before ArcGIS StoryMap was chosen as the development application for the digital exploratory environment, several other systems and applications were evaluated. Included in the other similar story mapping applications, were StorymapJS and MapJournal. Content management systems (CMS) were also evaluated, namely Drupal, Joomla, WordPress, Wix and Django. In choosing between a story mapping application and a CMS, story mapping was selected as it was better suited for specifically presenting geospatial content and offered hosting services with no additional cost, whereas the evaluated CMSs required incongruous extensions for working with spatial data and required hosting from third-party providers at a cost.

As both ArcGIS StoryMap and MapJournal are Esri products, they were the most compatible with the web maps (made through ArcGIS Online) and CityEngine 3D visualizations (developed using an Esri

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desktop application) that were created to be incorporated in the final product. Considering this, two versions of the story map with the same content were created - one using ArcGIS StoryMap and another using MapJournal Builder. These two versions were soft-launched to the *Metsemegologolo* team to gain feedback on preferences. ArcGIS StoryMap had a faster loading time, did not lag as often and had a more appealing visual aesthetic, so it was ultimately selected.

4.2.2 Spatial Data

The spatial data used in the web map includes the Seoke extent, stone walls as well as point data for all of the material findings in the Northern cluster (Section 3.1.4, Table 6). The stone wall data was provided by Stefania Merlo and was created from the digitization of aerial imagery in addition to an on-site survey with a hand-held GPS. The material findings in the Northern cluster include the point location of grinding stones, grain bins, quern stones, potsherds, lithic fragments, platforms, spears, sliding doors and other similar objects. As Seoke is a relatively new site in terms of study and data collection (Section 1.4; Section 2.1.3), the geospatial data presented in the story map only conveys the data available at this current stage of research. Metadata is available, especially for the data regarding the material findings in the Northern cluster of Seoke. Date/Time data of the collection of the geospatial data for various material findings are available in the story map.

4.2.3 Archive

There are several points in the story map that make links to a digital archive. The archive is being developed by Anton Coetzee, as a collaborator in the *Metsemegologolo* project (Section 1.1; Annex 1) for the exploration of cultural heritage, informing on history and other related humanities subjects. The archive holds archaeological objects related to the site such as museum objects, findings from recent excavations, 3D models, geospatial data, aerial imagery, photographs, archival documents and published papers. These objects inform on indigenous art forms, linguistics, ancient foodways, environmental adaptation and concepts of home and power (Metsemegologolo, 2021). The curation of access to specific materials in the archive through links in the story map provides archaeological, academic and archival access to Seoke. Structurally, for every object in the archive, there are descriptions, links to sources, and relationships with other objects in the archive.

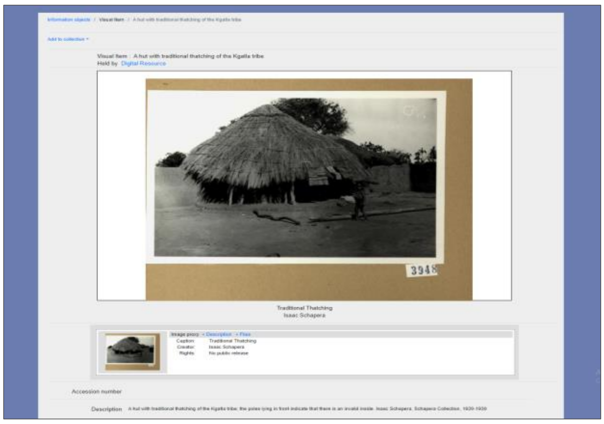

Figure 21. Visual Item in the Metsemegologolo Archive

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4.2.4 Media Elements

The various media elements in the story map serve to create a visual reference to the objects, places and people discussed in the text. The images in the story map include archival photographs, recent images of the site as it appears now as well as images of the 3D visualization in cases where there are no relevant images available.

The 2D web maps were created using the ArcGIS MapViewer or were made directly in ArcGIS StoryMap. The 2D maps in the story map were used mainly to orientate the viewer as to the location of Seoke in addition to the physical environment and extent of the site. As the site is not built-up, using a base map of aerial imagery clearly showed the terrain, vegetation and rivers in the area, with better detail than a vector base map. The stone wall and material findings data were superimposed on the base map. The web maps allow users to click on features to bring up their attribute data as a pop-up, allowing important attributes such as the date of data capture to be available to a viewer.

Two interactive 3D visualizations were added to the story map using CityEngine Web Viewer. Cognitive overload was a concern, as discussed in Sections 2.3.2 and 3.3., because of the unknown spatial abilities of the target users. Manipulation of dynamic 3D models and immersive 3D were, in particular, were issues of concern. Thus, the visualizations are both simple and small in size to minimize any cognitive overload issued that a user may experience, with the added benefit of a faster loading time. Users can pan, rotate and zoom in these simple visualizations, but can also use the autoplay feature that automatically moves the visualization to key parts of the scene. The first visualization (available at: https://bit.ly/3s0l1fv) is of a dwelling and includes a stone enclosure, midden, grinding stone, pot and grain bin (Figure 22). Each object in the visualization has an info pop-up that explains what the object is, what it is made up of and how it was used. The second interactive visualization (available at: https://bit.ly/2YDpGdH) is of the terrain of Seoke (Figure 23). The various hills in the settlements played important roles for the Bangwaketse as defensive structures. The visualization displays the terrain of all of the larger clusters of stone walls found at the site.

Figure 22. Interactive Dwelling Visualization

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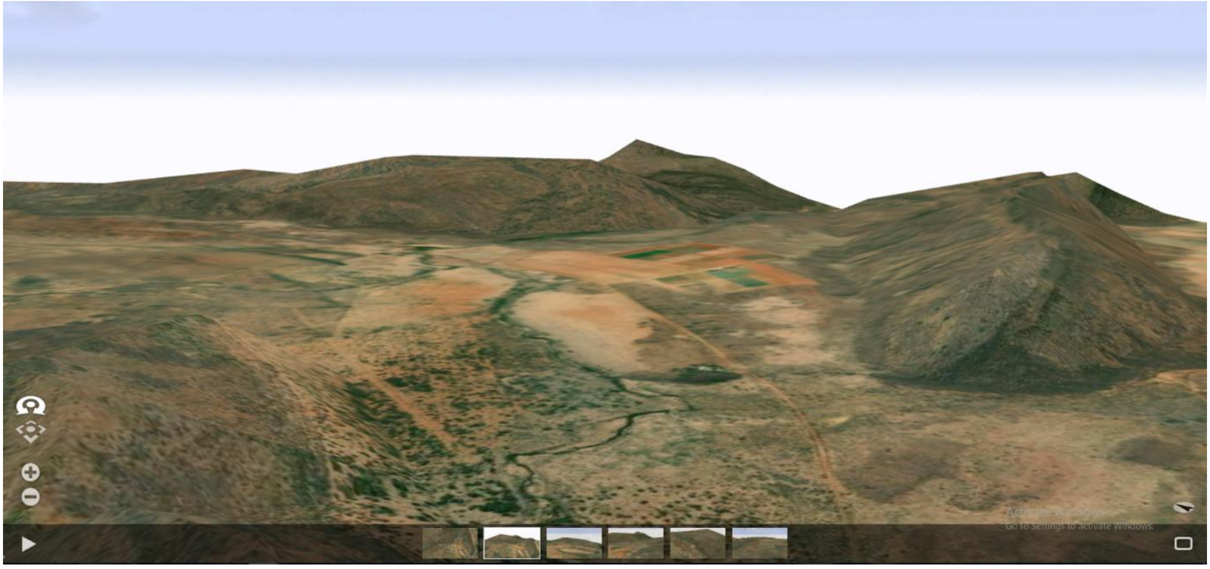

Figure 23. Interactive Terrain Visualization

As discussed in Section 3.2.1, the Northern cluster of Seoke was selected for the portrayal of a 3D scene as a solution for the loading and distribution issues that arose for a 3D scene for the entire site of Seoke. The visualization of the Northern cluster is detailed and complex, containing hundreds of different objects. As such, the exported file is quite large. This made it difficult to link an interactive 3D scene of the Northern Cluster in the same manner as with the dwelling and terrain visualizations. CityEngine Web Viewer recommends a maximum file size of 20MB for web scenes. However, the 3D web scene for the Northern Cluster was upwards of 200MB. As the story map is intended to be distributed and viewed online, having users load such a big file would be an issue. As a work-around, a video was created that displayed all of the different components of the Northern cluster visualization (available at: https://youtu.be/z3Gnbqz7xlU).

Using the CityEngine desktop application, screen recordings were made moving through different sections of the Northern cluster 3D scene. These screen recordings were compiled into a short video using Adobe Spark. As the story map was to be evaluated through eye tracking, it was decided to include a voice-over to describe the video content, rather than annotations. For the video voice-over, a script was written out with input from Metsemegologolo collaborators (Annex 1) Stefania Merlo and Fred Morton. To select an individual for the voice-over recording, a request was sent out via email to several *Metsemegologolo* collaborators to send a sample clip reading out an excerpt from the script. Jennifer Fitchett was ultimately selected. Once received, the audio recording was cleaned to remove any noise using BandLab, an online application. The video and voice-over audio were compiled together using MiniTool MovieMaker to produce the final product, which was then uploaded to YouTube and embedded into the story map.

4.3 Evaluation

4.3.1 Structure

The final story map product can be found here (available at: https://arcg.is/0SDaaO). The narrative of the story map is organised concisely into clear introduction, body and conclusion sections. The

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introduction of the narrative orientates the viewer to the location of Seoke in relation to the world. The value of studying Seoke is also introduced in the broader context of studying pre-colonial southern African settlements such as Mapungubwe and Great Zimbabwe. The main characters of the narrative, the Bangwaketse, are introduced. The power, influence and activities of the Bangwaketse in the region are addressed. As part of the body, the narrative introduces the stone walls of Seoke as the most apparent remains of the settlement. In establishing the foundation of the state of the site in current times, other related topics can be discussed. The body presents knowledge-based evidence and assumptions that work to simplify the conceptualization of an inhabited Seoke for the viewer. The evidence and assumptions presented include the other archaeological findings found at the site, what dwellings looked like and how they were arranged, how the physical environment was utilized, agricultural practices and the wealth of the Bangwaketse. The conclusion spatially organizes all of the knowledge gained in the body of the story map into a 3D scene. There are tabs along the top of the page that makes navigating the different topics in the story map easier (Figure 24).

4.3.2 The Variety of Media

The story map displays multiple forms of media to support the narrative. The layout of the story map is made of two panels. Textual information is located in the narrower panel on the left and is substantiated by several images and maps in some sections. The wide panel on the right is the main stage where most of the maps, images and videos are located. All maps and images are credited through an information icon at the top left of the image. The 3D visualizations are accessed through buttons in the story map that open the visualizations in a new tab (Figure 24). Previous iterations of the story map displayed the 3D visualizations in the main stage as an embed rather than having it open in a new tab. Although having the visualization on the main stage was more convenient for the reader, the load time became an issue. Opening the 3D visualization in a new tab allowed the scene to load faster, lessening the frustration for the reader. Furthermore, an additional 3D visualization of the site is available in the form of a video about the Northern Cluster of Seoke.

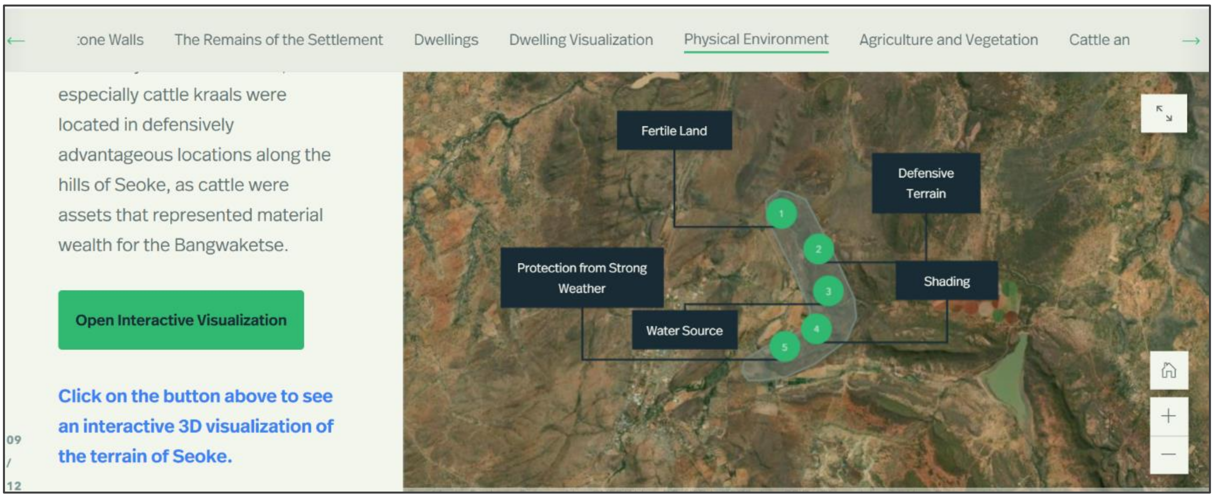

Figure 24. Excerpt from the Story Map

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4.3.3 Links to the Archive

In cases where the images exist as objects in the archive (see Section 2.3), links are available that will direct the user to its location in the archive. Similar to the buttons for the 3D visualization as mentioned above, the archive can also be accessed through buttons located in the story map (Figure 25). By clicking the button, viewers will be directed to a related object in the archive. Photographs, spatial data and academic papers were uploaded to the archive as *Information Objects.* The archive provides information such as an object description, author and source with some objects being downloadable (Figure 21).

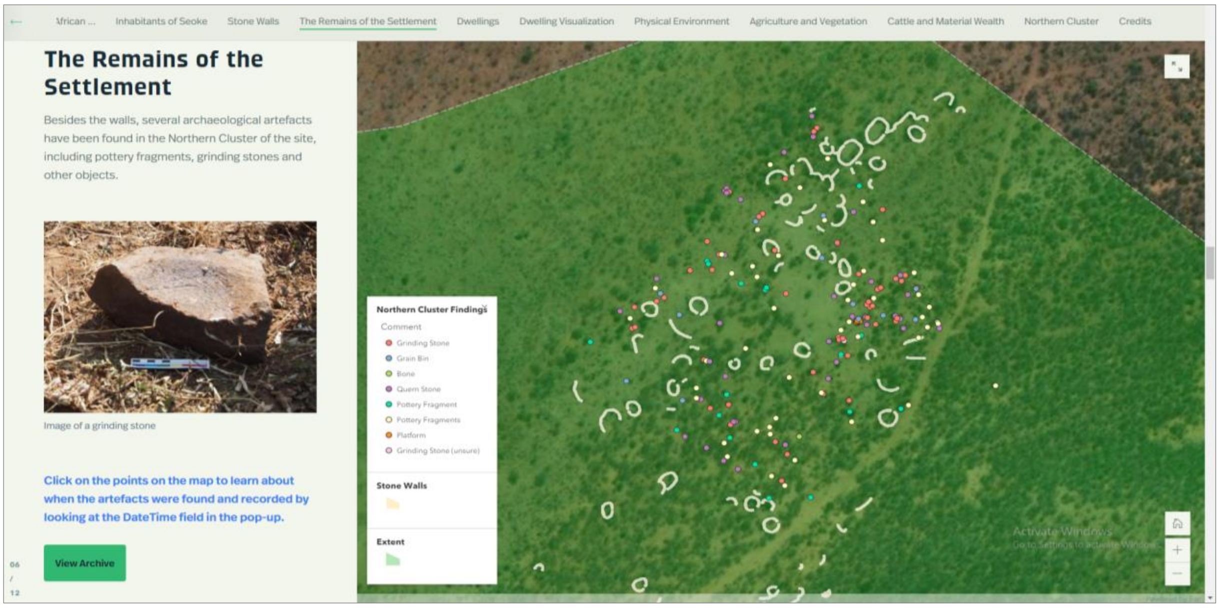

Figure 25. Archive Access Button in Story Map

4.4 Summary

The historical, archival and academic information available regarding Seoke and the Bangwaketse is technical and niche. As the information is historical, it may be especially difficult for an individual who is not knowledgeable about pre-colonial southern African history to conceptualise the information in reference to experiences in their daily lives. The exploratory environment was presented as a story map where spatial data-driven storytelling in combination with various forms of engaging media was utilized in an effort to making the dissemination of information more natural (Berendsen et al., 2018). Educational material about Seoke and the Bangwaketse was presented through the main narrative of the story map in addition to supplementary and auxiliary contents such as archival links and 3D visualizations, both interactive and video.

Story maps have been found to be an ideal educational tool, effective for communicating geospatial information (Berendsen et al., 2018), for the conceptualization and reinforcement of information learned and for confidence in knowledge gained (Groshans et al. 2019). As for this multimodal story map in particular and the intended audience's reactions to it, further evaluation will be conducted and discussed in Chapters 5 and 6. As the intended users of the story map are a diverse group demographically (university students of different academic backgrounds, from different universities in South Africa and Botswana), there are far more variables that can affect the story map's effectiveness, efficiency or user satisfaction as an educational tool. Furthermore, as a multimodal product, the story map's incorporation of 2D maps, images, 3D visualizations, video and archival links present unique conditions for its evaluation. As such, it is important to determine if a story map can be an ideal educational tool in the context of its idiosyncratic theme, presentation and intended audience.

As to the content of the text and multimedia, and its objectivity, subjectivity and inclusivity, Warner-Smith (2020) highlighted the need to remove the voice of the researcher as the primary narrator of story maps. Relatedly, the personal choices of the developer should be minimal while transforming a story into spatio-temporal units (Caquard & Dimittrovas, 2017). Hence, the narrative informs readers about the settlement while subjectively positioning the Bangwaketse as the main characters of the narrative, using original place names and nouns where possible. The narrative was written in part by academic experts regarding Seoke, the Bangwaketse and southern African stone-walled sites (Annex 1 - namely Fred Morton, Stefania Merlo, Amanda Esterhuysen and Justine Wintjies) and the phrasing of the narrative was iteratively improved upon.

However, the story map is a curation of historic, academic and archival information currently available for Seoke and the Bangwaketse. As a consequence, the level of detail in the story map and its content such as maps, visualizations and video are limited, especially as learners can easily become overloaded when confronted with a lot of information at once (Jardodzka et al., 2017). To mitigate this, the archival links and attributions in the story map provide a starting point for users who are seeking to learn more, beyond the scope of the story map. Furthermore, access for primary stakeholders is limited as the story map and other texts (i.e., map labels, video voice-over, etc.) are currently only available in English. As the Bangwaketse are a Setswana-speaking people, and Seoke is a historical site of Botswana, providing Setswana as a language option for the story map will improve its accessibility and inclusivity.

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Chapter 5: Usability Survey

This chapter discusses the approach to determining the usability of the final story map product through a user survey. Usability assessments are crucial for evaluating a developed product against its intended functions. In this case, this chapter delves into the usability assessment of the story map, which was developed to be an exploratory digital environment for learning about Seoke, a pre-colonial southern African settlement. The requirements section lists the various components of the story map for which the usability will be assessed. The development of the usability survey questionnaire and how it was distributed are outlined in the development section. The results section reports on the findings of the questionnaire to determine the usability of the story map overall and as an educational tool. Lastly, the discussion section elaborates on how effectively and efficiently users learned in addition to user satisfaction while learning.

5.1 Overview

The purpose of the usability survey is to test and analyse the usability of the story map as an exploratory digital environment for learning. As a digital platform centred around the activity of learning, the story map must be evaluated on its usefulness and usability in facilitating learning. In this regard, the effectiveness, efficiency and user satisfaction of the story map will be assessed. Information and knowledge retention is a major indicator of platform usability in education (Van Nuland et al., 2017), and will be highlighted in the evaluation as well.

5.1.1 Outline

The usability of the story map will be evaluated across three distinct areas, namely:

<u>i) Calculate the System Usability Scale (SUS) scores:</u> Firstly, calculate average SUS scores and item-level ratings to identify how well the platform performed based on established metrics and norms of system usability. At the item level, identify system-level qualities of usability that performed especially well or especially poorly.

<u>ii) Identify the level of information retention and learner confidence:</u> Next, determine how well readers learned by testing information retention. Information retention and learner confidence will be evaluated by the participants' scores on a short test and their self-evaluated confidence scores for their answers.

<u>iii) Identify perceptions of value and knowledge gained:</u> Lastly, identify if participants' attitudes towards the value of the story maps and knowledge gained. Additionally, determine whether any perceptions about the topics covered in the story map were present and if the story map changes those perceptions.

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5.2 Development

5.2.1 Procedure

A questionnaire (Annex 13) was generated using Qualtrics XM, which is a web-based surveying tool. The questionnaire is split into 5 sections, namely demographics, usability, 3D visualization, value and perception (Table 8).

Table 8: Summary of the Usability Questionnaire

Section	Number of Questions	Question Type	Intended Outcome
Demographics	17	Multiple-choice & text	Gather participant's non-personal details and information regarding prior academic and system experiences.
Usability	10	5-point rating (SUS questionnaire)	Gather feedback for the story map's system-level usability.
3D Visualization	12	Multiple choice, percentage rating	Evaluate participants' level of information retention and confidence in submitted answers.
Value	5	5-point Likert scale	Gather participants' feedback on the pedagogical value of the 3D visualization and the story map.
Perception	9	Multiple-choice & 5-point Likert scale	Evaluate how participants perceive the 3D visualization, pre-colonial Africa and what was learned from the story map.

First, the demographics section consisted of 17 multiple choice and text questions intended to collect non-personal data about participants. Basic questions about age, gender, institution and academic course were asked. Besides this, participants were asked about their comfortability with English and with using a computer, the amount of sleep they had the night before, if they are colour-blind and if they wear prescription lenses or contacts. Questions were also asked about their academic history and general prior experiences, such as if they have experience with story maps, 3D models or with Google Earth. Participants were also asked about their interest level in the topic of southern African pre-colonial history and their prior knowledge about southern African pre-colonial settlements. Secondly, the usability section consisted of a standard, five-point scale, 10-item SUS (Brooke, 1996) that was linguistically adjusted to have '*story map*' as the subject of the questions. Thirdly, the 3D visualization section consisted of 12 questions in total that tested the participants' information retention through a short test. A test of six multiple-choice questions presented various excerpts from the 3D visualization and asked participants to either identify the objects or to locate where an object should be placed in the scene. For each question, the participant was asked to self-evaluate how confident they were with the answer they provided using percentage ratings. Next, the value section consisted of five questions that asked participants to rate the value of the 3D visualization and story map using a five-point Likert scale. Lastly, the perception section consisted of eight multiple-choice and five-point scale questions that asked participants about their opinions of the 3D visualization and models. This section also asks participants about their perception of pre-colonial southern Africa and if they feel that they learned by reading the story map. Participants were also permitted to write a comment at the end of the questionnaire if they wished to share any additional information.

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5.2.2 Distribution

The questionnaire, accompanied by the story map, was distributed to students at the University of Witwatersrand, University of Pretoria and the University of Botswana via email. For the University of Pretoria, the recruitment email was distributed, with ethics clearance (Annex 13), using the *'Department of Geography, Geoinformatics and Meteorology 2020'* mailing list. Similarly, for the University of Witwatersrand, the recruitment email was distributed with, ethics clearance (Annex 14), using the *'Faculty of Humanities'* and *'Faculty of Science'* mailing lists. For the University of Botswana, participants were recruited with the help of Keletso Setlhabi, who is a collaborator for the *Metsemegologolo* project (Section 1.1; Annex 1). The target participants of the usability survey were university students who are not specialists or are not thoroughly knowledgeable about pre-colonial southern African history. As Seoke became the subject of study in 2012 (Sections 1.4 & 2.1.3), university-level students will not be familiar with the site in particular.

In the recruitment email, students were informed of the purpose of the study and how to participate. Participants were instructed to go through the story map (the stimulus) in its entirety and to then answer the questionnaire. A participant consent form was attached to the beginning of the questionnaire and students had to confirm their consent before starting the questionnaire. The consent form reiterated that participation is completely voluntary, that responses will remain anonymous and that they may opt to stop participating at any time.

5.2.3 Participants

A total of 111 students participated in the usability survey. Of the participants, 32% were male and 63% were female. The remaining 5% preferred not to say, preferred to self-describe or identified as non-binary. The average age of all of the participants was 23 years. The age values did have a large range of 34 as some postgraduate students participated (Table 9).

Table 9. The Gender and Ages of the Participants of the Usability Survey

		University of Botswana	University of Pretoria	University of Witwatersrand	Overall
Gender	Female	5	16	49	70
	Male	6	7	22	35
	Other	2	1	3	6
Age	Mean	23,5	20,8	23,0	23
	Min	18	17	18	17
	Max	38	35	51	51
	Std.Dev	6,27	3,61	7,18	6,50

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Almost half of the participants were first-year students (Figure 26). The rest of the participants were mainly Masters, fourth-year/Honours or third-year students. Lastly, a few participants were second-year or PhD students. Of the participants, 67% were students at the University of Witwatersrand, 21% at the University of Pretoria and 12% at the University of Botswana.

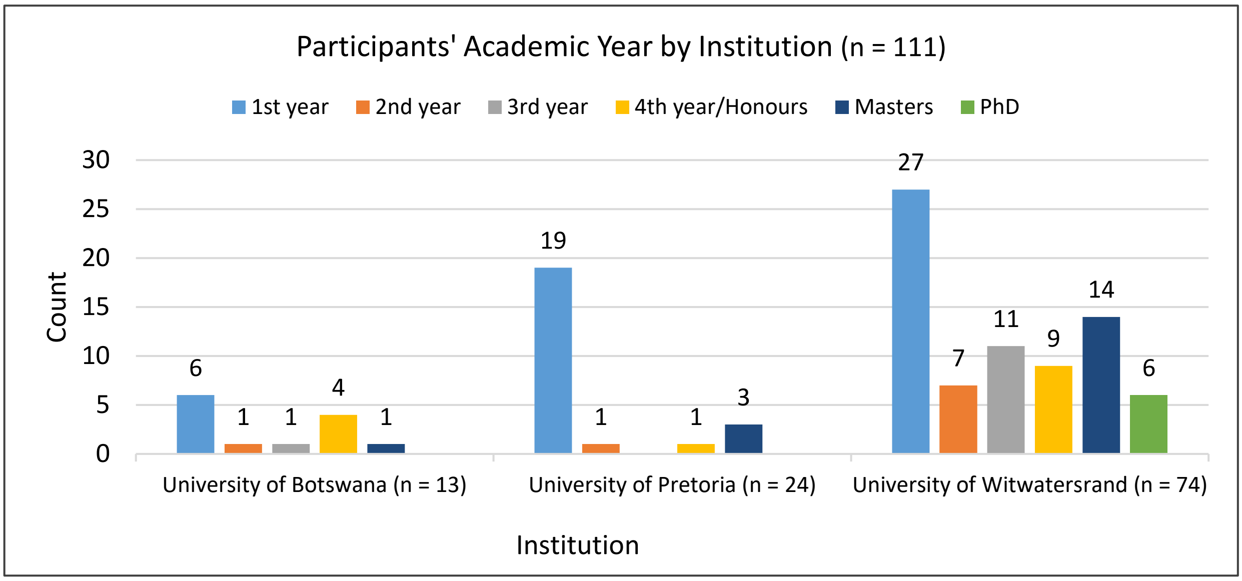

Figure 26. Participants' Current Academic Year

Participants were registered for various courses at their respective universities. 18% of participants were enrolled in courses that provide some exposure to story mapping, 3D visualization or pre-colonial southern African history (Figure 27). Such courses include Archaeology, Geography, Environmental Science, Geoinformatics and Meteorology. The remaining 82% of participants were enrolled in other courses (Figure 28). These various courses are visualized in Figure 29.

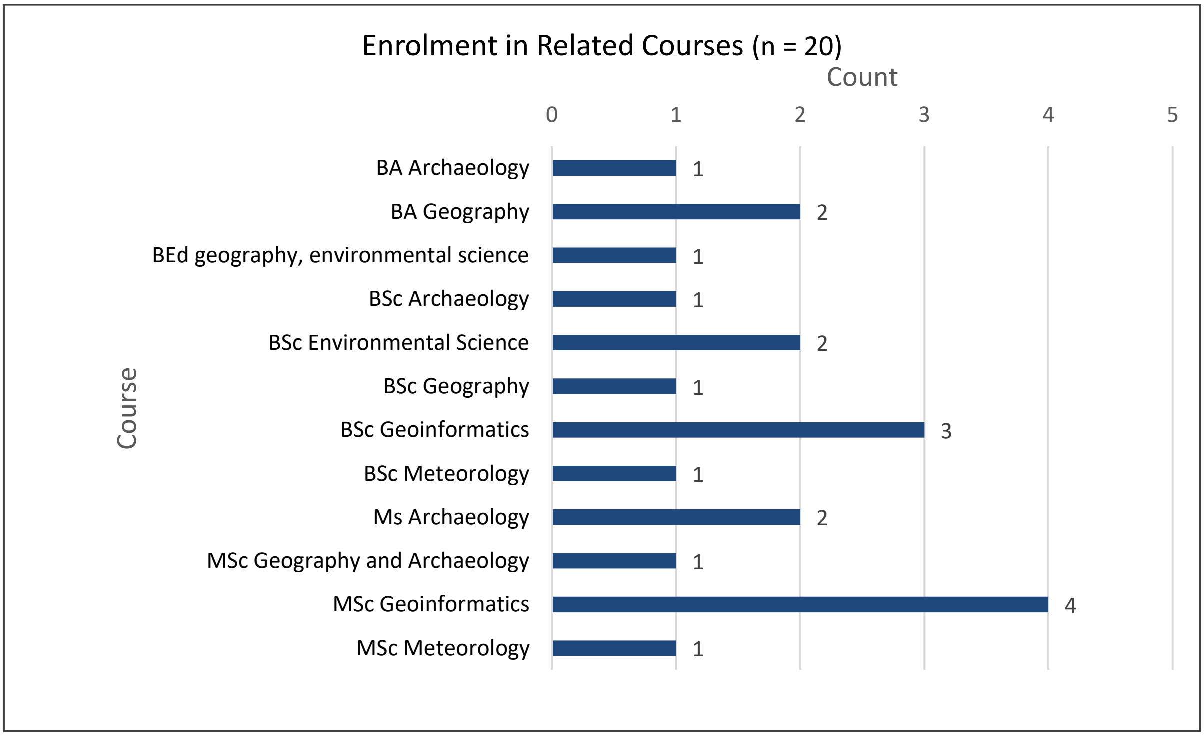

Figure 27. Participants Enrolled in Courses with Some Relation to the Story Map

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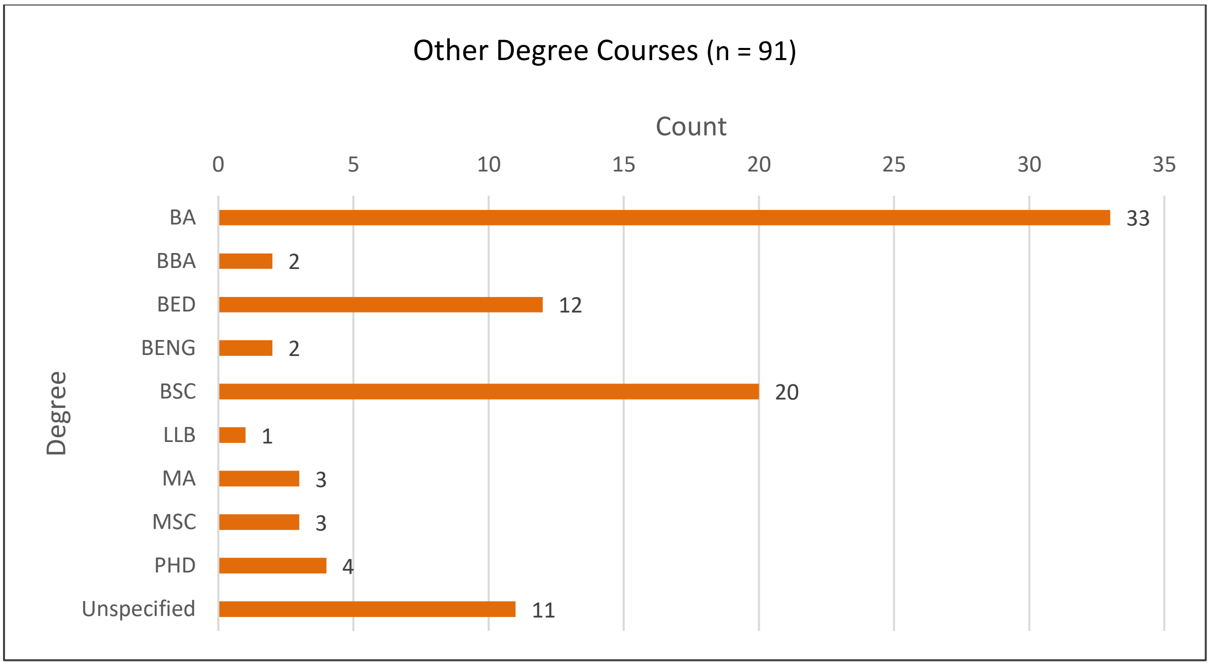

Figure 28. Participants Enrolled in Other Courses

Figure 29. Visualization of Participants' Registered in Other Courses at University

In this regard, participants were asked if they had taken some modules that cover the themes or subjects presented in the story map. The highlighted modules include those related to Seoke and the Bangwaketse (archaeology, southern African pre-colonial history and urban geography) or the physicality of the site (physical geography, and GIS or remote sensing). Approximately 65% of the participants responded that they had not taken any of the above-mentioned modules (Figure 30). Of the remaining 39 participants who have completed a related module, physical geography received the most responses with 23. Urban geography and GIS or remote sensing both received 18, southern African pre-colonial history received 15 and Archaeology received the least, with seven responses.

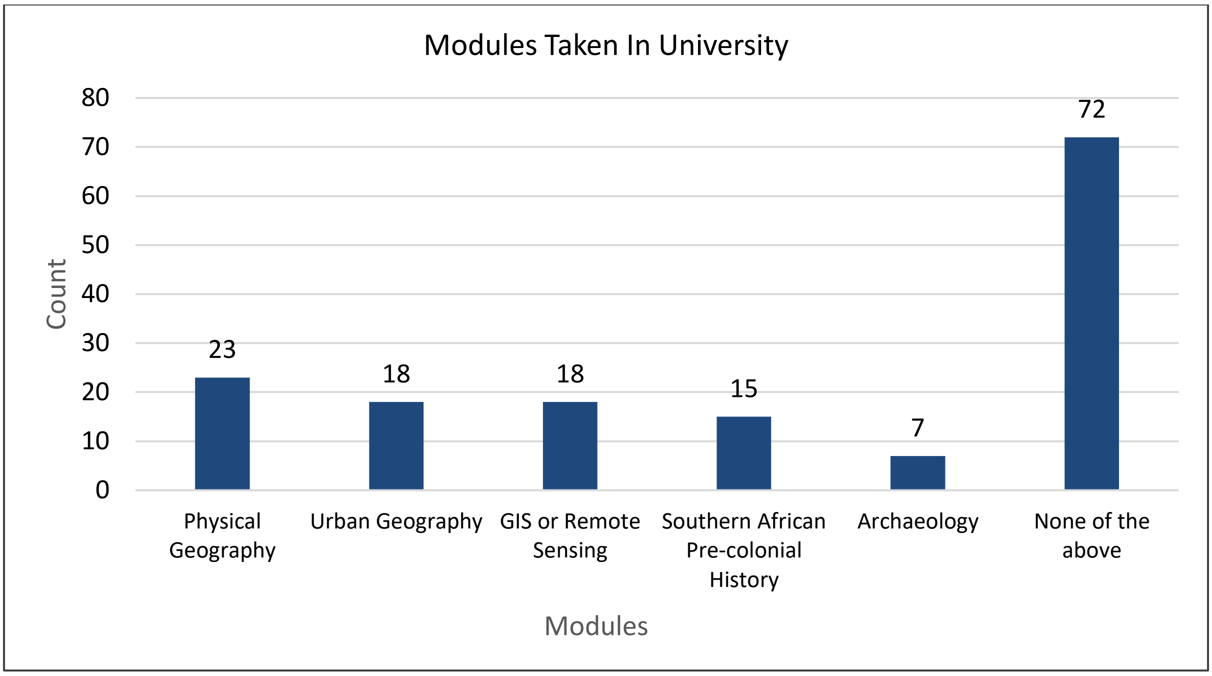

Figure 30. Modules Completed by Participants at University

Similarly, when asked directly about their prior knowledge about pre-colonial southern African settlements, the majority reported that they had *moderate* knowledge or less, which encompassed 86% of participants. Of the remaining participants, 11% reported that they knew *a lot* and only 4% reported that they knew *a great deal* (Figure 31).

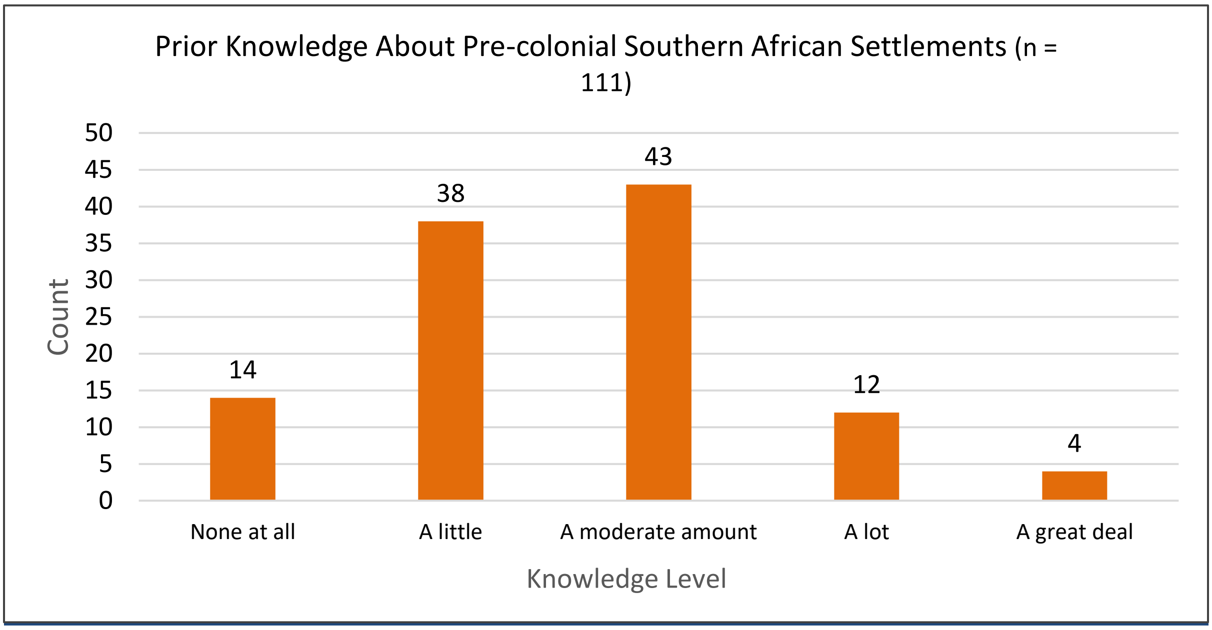

Figure 31. Prior Knowledge About in Pre-colonial Southern African Settlements

In Sections 1.1, 4.1.1 and 4.4, the intended user of the story map was introduced and discussed. The intended user of the story map and the target audience for the usability study are individuals who are not specialists or are not knowledgeable about pre-colonial southern African history or Seoke specifically. Regarding expertise or academic exposure to Seoke specifically, having knowledge of pre-colonial southern African history would give context to understanding information about Seoke. However, as part of archaeological research in southeast Botswana that started in 2012, Seoke and

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other related sites have been recorded relatively recently and information about these sites is not widely known (Morton & Merlo, 2015; Biagetti et al., 2021).

Several participants self-reported some level of experience within several contexts. Of the participants who had reported that they had completed a module regarding pre-colonial southern African settlements (Figure 30), the largest proportion were first-year students at 33%. Because of the time of year in which the survey was conducted, it can be assumed that these participants either completed a short course on the theme or are currently enrolled in the module. Besides this, 27% were third-year students, 13% were fourth/honours students, 20% were masters students and 7% were PhD students. Although these participants reported that they had completed a module on pre-colonial southern African history, none of the participants self-evaluated themselves as having *a great deal* of knowledge on pre-colonial southern African settlements, which was the highest self-rating option provided. Among those who reported that they had completed a module on pre-colonial southern African history, 47% reported their knowledge as *moderate* and 33% as *a lot*. 20% rated their knowledge as *a little* (Figure 31).

As most of the participants had not completed any modules covering archaeology or southern African pre-colonial history, most of the participants did not have much prior knowledge about pre-colonial southern African settlements (Figure 31). However, the interest level in the topic was not limited by the lack of prior knowledge, as over 90% of participants showed some level of interest in the topic (Figure 32).

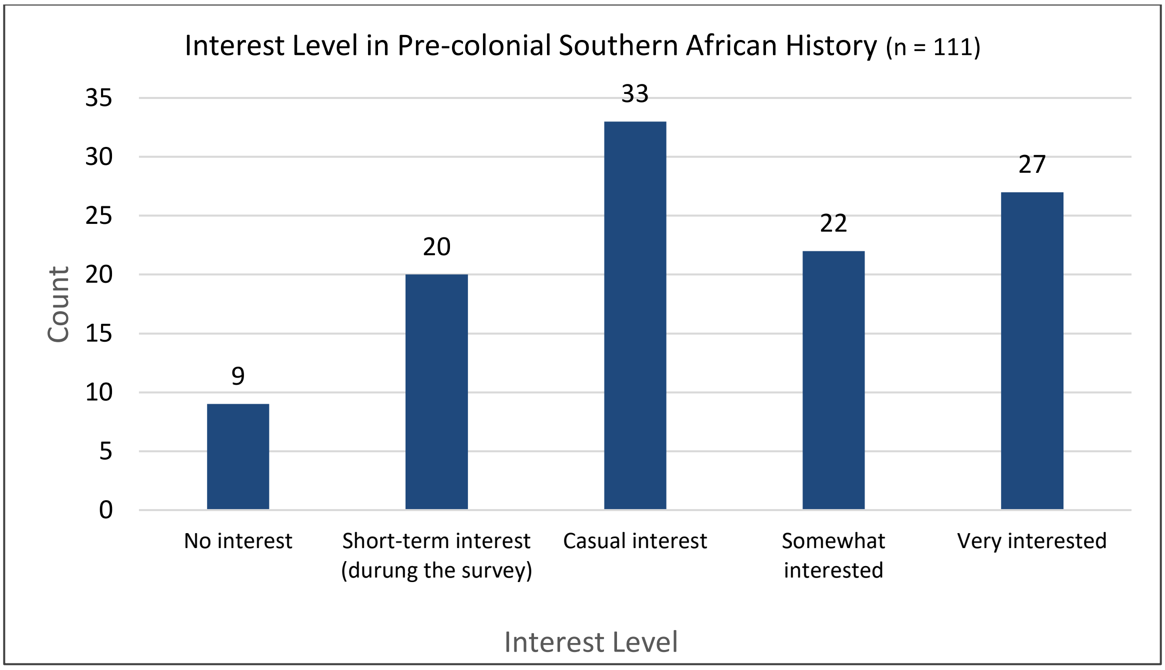

Figure 32: Interest Level in Pre-colonial Southern African history

Relatedly, participants were asked about their practical experience levels with story maps, 3D models and Google Earth. Google Earth was used as a benchmark for experience with interactive web maps and aerial imagery, considering that Google Earth is a popular and commonly used application in this regard. Approximately 85% of participants had no prior practical experience using or creating a story map before. For using or creating 3D models, approximately 71% had no prior practical experience.

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The participants had the most experience with Google Earth, with only 34% having no prior practical experience using the program (Figure 33).

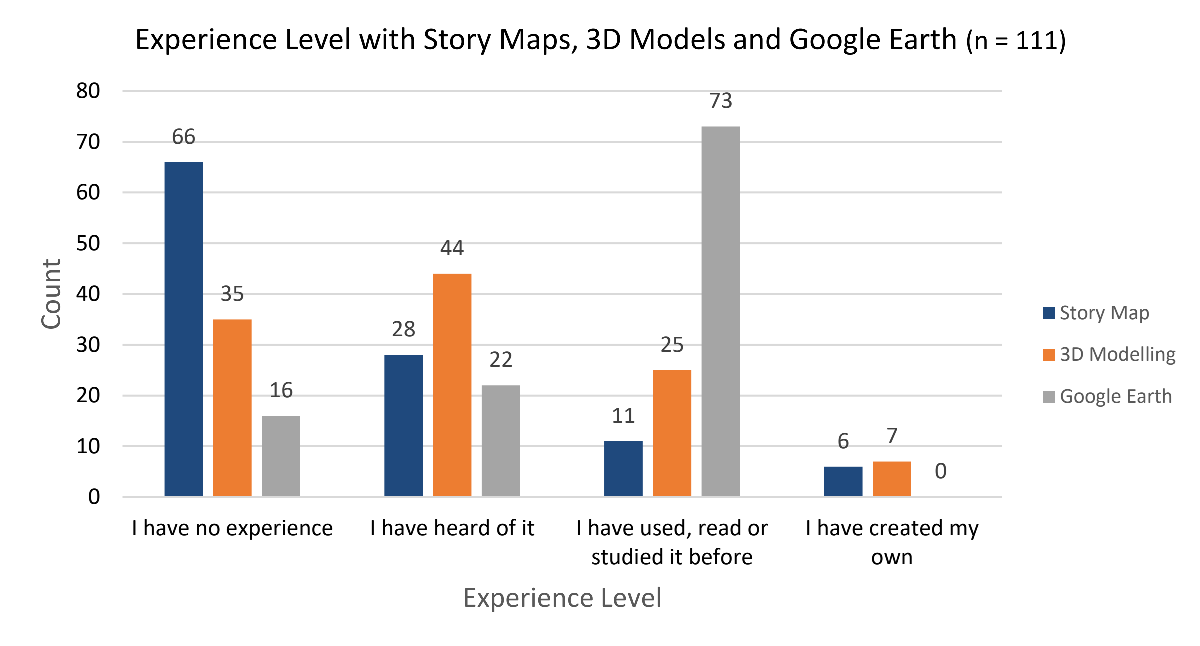

Figure 33. Participants' Experience Level with Story Maps

Participants were also asked about their comfortability with the mediums used to conduct the usability survey, namely English and computers. This was important to establish due to the diversity of the participants as implied by the fact that they were recruited from three different universities in two countries and are enrolled in a variety of courses. When rating their comfort level with English and with using a computer, 80% and 77% respectively, rated their comfort level as very comfortable or comfortable (Figure 34).

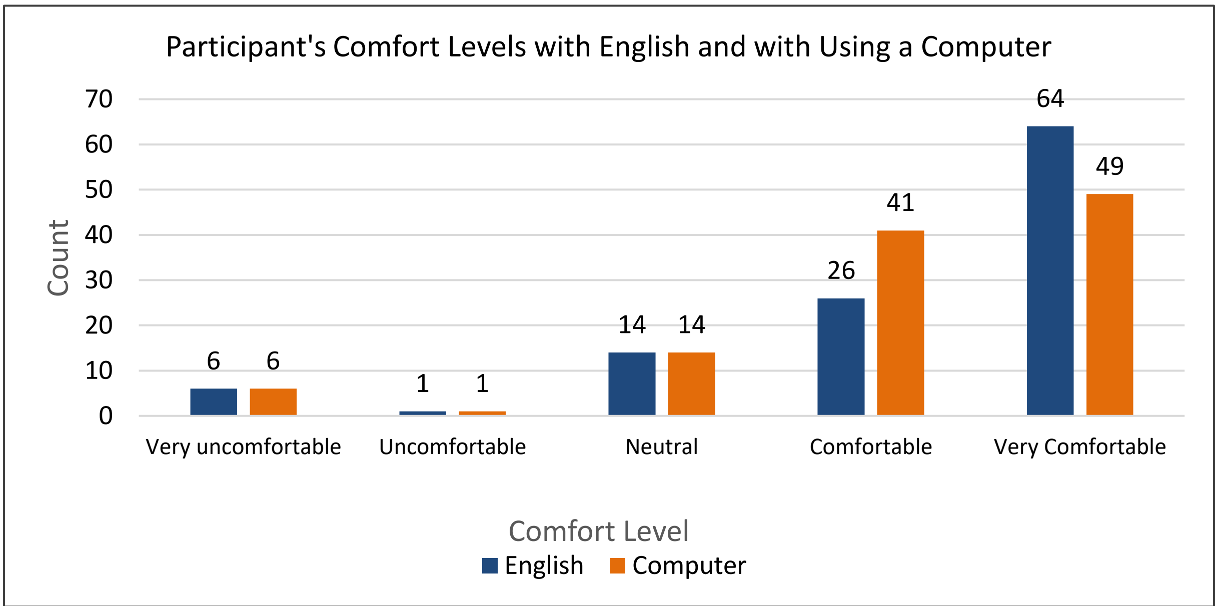

Figure 34. Participants' Comfort Level with English and with Using a Computer

5.3 Results and Evaluation

5.3.1 System Usability Scale (SUS) Scores

5.3.1.1 Overall SUS score

The System Usability Scale (SUS) is a usability assessment tool developed by Brooke (1996). The SUS questionnaire prompted participants to answer 10 usability questions about the story map in alternating positive and negative toned questions, referred to as 'items'. Participants' ratings in this regard were used to calculate the average SUS score. An overall SUS score was calculated for each participant. The equation (Brooke, 1996) uses the sum of the positively toned items (items 1, 3, 5, 7, and 9) and the sum of the negatively toned items (items 2, 4, 6, 8, and 10). The sum of the negatively toned items is subtracted from the sum of the positively toned items. 20 is then added to this value, which is then multiplied by 2.5 to adjust it to a value that will fall between 0 and 100. The participants' overall scores were then averaged to calculate the average SUS score for the story map. The average SUS score was calculated to be 65. Through evaluation against established norms, a score of 65 places the usability of the story map in the 41 -59 percentile, awarding it a grade of C, according to the Sauro et al. curved grading scale for SUS scores (2016). Using the Bangor et al. adjective rating scale (2008), an average SUS score of 65 can be described as *'Good'*. Most of the SUS scores calculated for the participants ranged between the 40 - 80 range (Figure 35). Approximately 42% of the participants scored the story map with a SUS score of above 68, which is the 50th percentile. Furthermore, 24% of the participants scored the story map with a SUS score of over 80, which is an A grade. The distribution of SUS scores according to the Sauro et al. curved grading scale (2016) can be seen in Figure 36.

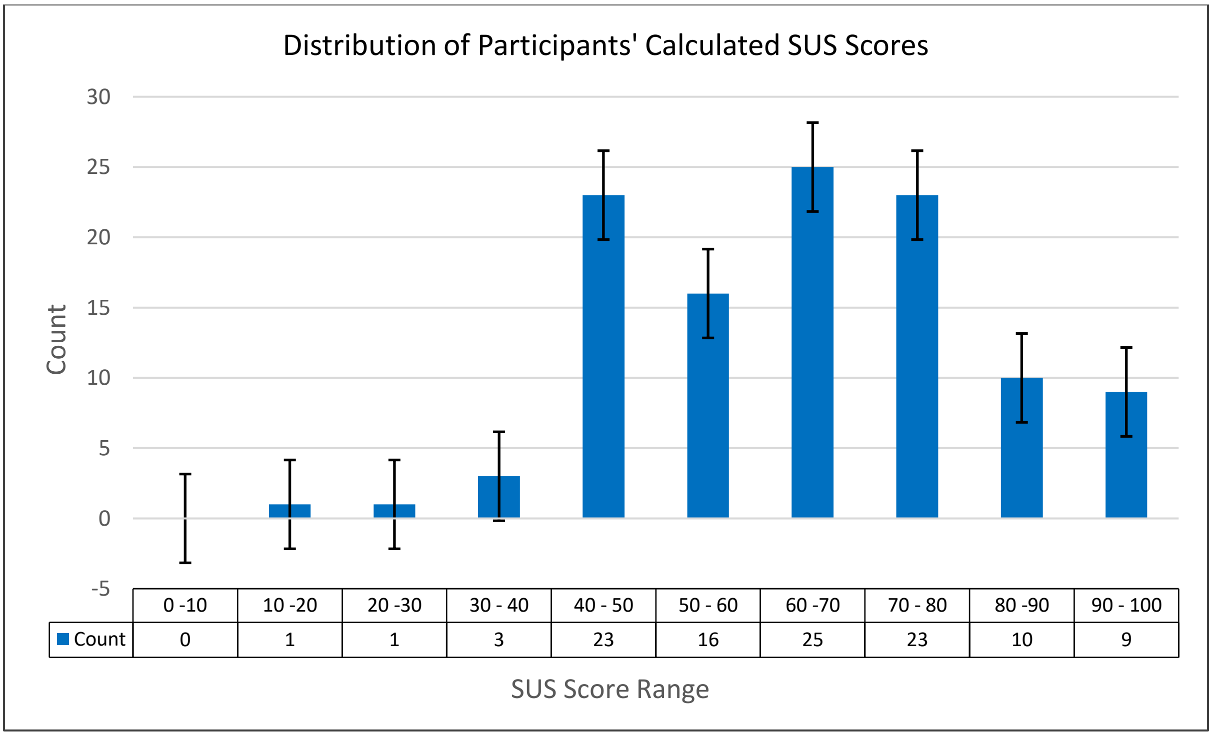

Figure 35. Distribution of SUS Scores

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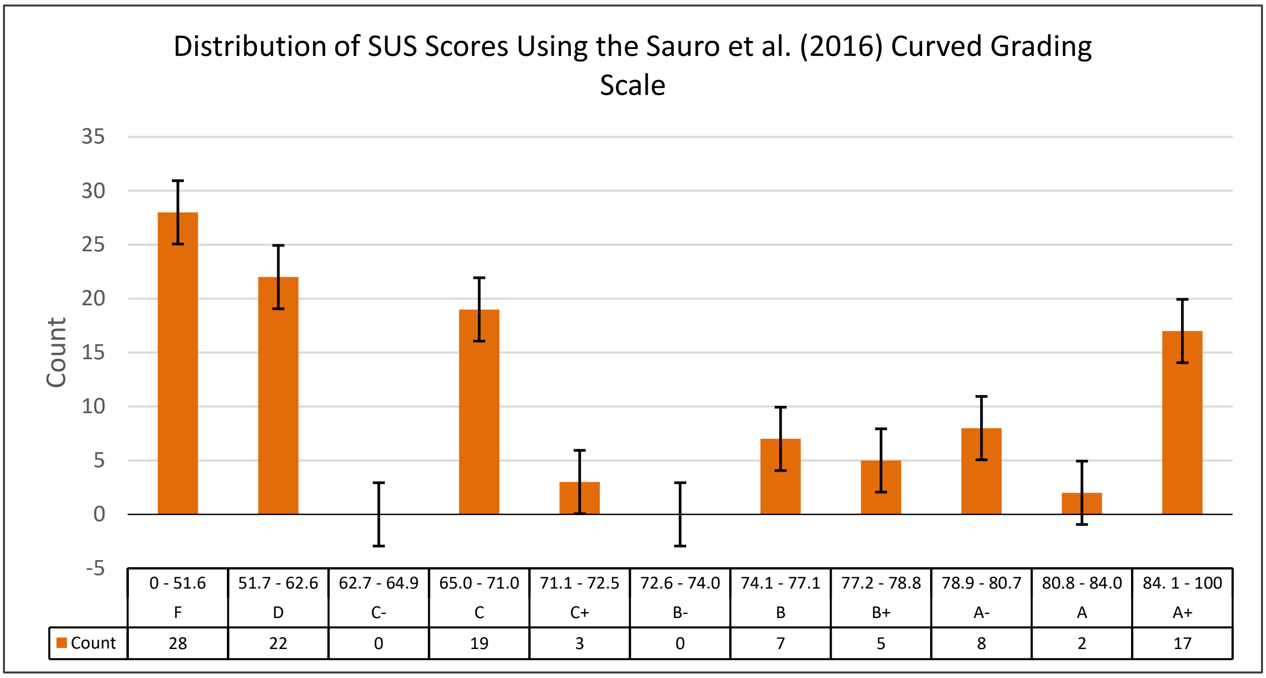

Figure 36. Distribution of SUS Scores Based on the Sauro et al. (2016) Curved Grading Scale

5.3.1.2 Average Item Scores

On its own, the calculated overall SUS score of 65 is a broad descriptor of the story map's usability as a system. Alone, there is no insight given into items (questions) of interest that may have performed particularly poorly or particularly well and thus contributed to the overall calculated score. To gain further insight into the calculated overall SUS score of 65, participants' responses were analysed at the item level. Using the average item score for each of the 10 questions in the SUS questionnaire, an average SUS score that correlates to the item averages were calculated using simple linear regression equations (Lewis & Sauro, 2018).

In simpler terms, the average score that participants gave to each SUS question was used to calculate the overall SUS value that matches it. As such, it can be seen if an item average score is that of a SUS score that can be described as *Excellent*, *Good*, *OK*, *Poor* or *Worst Imaginable* (Bangor et al., 2008), highlighting specific items to take note of. The results cannot reveal the exact reasons as to why participants scored the items in this manner. However, inferences can be made based on the story map's system qualities or known challenges faced in the iterative development of the final product. Mostly, the average SUS scores and the item level averages can be used as indicators of where improvements should be made. For interpretation, the average item scores were compared to the benchmarks of an average/C grade SUS score (68) and an A grade SUS score (80), based on the curved grading scale by Sauro et al. (2016).

As seen in Table 10, at the item level, it was found that four items performed better than the benchmark for a SUS score target of 68. These items (Brooke, 1996) are:

i) Item 1: I think that I would like to use this story map <u>frequently</u>.
ii) Item 2: I found the story map unnecessarily <u>complex</u>.
iii) Item 3: I thought the story map was <u>easy to use</u>.
iv) Item 5: I found the various functions in this story map were <u>well integrated</u>.

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One item matched the upper limit for a target SUS score of 68.

v) Item 7: I would imagine that most people would learn to use the story map very quickly.

Five items performed worse than the benchmark for a target SUS of 68. These items include:

vi) Item 4: I think that I would need the support of a technical person to be able to use the story map.

vii) Item 6: I thought there was too much inconsistency in the story map.

viii) Item 8: I found the story map very cumbersome to use

ix) Item 9: I felt very confident using the story map

x) Item 10: I needed to learn a lot of things before I could get going with the story map.

Table 10. Item Average Scores and SUS Score Calculated from Item Average

Item Description	Item Average Score (Lewis & Sauro, 2018)	Calculated SUS Score Corresponding to the Item Average (Lewis & Sauro, 2018)	Curved Grading Scale (Sauro et al., 2016)	Adjective Rating Scale (Bangor et al., 2008)
1. Frequency of use	3.56	73.0	B-	Excellent
2. Unnecessary complexity	2.29	71.2	C+	Good
3. Ease of use	3.78	70.3	C	Good
4. Technical support	2.53	43.8	F	OK
5. Integration	3.78	74.8	B	Excellent
6. Inconsistency	2.31	64.9	C-	Good
7. Learnability	3.74	68.7	C	Good
8. Cumbersomeness	2.43	64.2	C-	Good
9. Confidence	3.66	66.7	C	Good
10. Prior knowledge needed	2.77	49.8	F	OK

Note: Red = worse than target SUS of 68 (50th percentile); Green= better than or equal to target SUS of 68

As an educational tool, conciseness, ease of use and simplicity are crucial characteristics of a platform to facilitate learning (Van Nuland et al., 2017; Jardodzka et al., 2017). A platform with these characteristics presents information in a manner that makes the search for information clear, especially for individuals exposed to unfamiliar educational content; in this case, those who are not

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knowledgeable about pre-colonial southern African history. The item level scores show that the story map performed above average in terms of frequency of use (Item 1), complexity (Item 2), ease of use (Item 3), integration (Item 5) and learnability (Item 7). Ease of use, learnability and appropriate complexity are characteristics that mitigate some of the negative feelings a student may experience while learning such as confusion, anxiety or frustration. These feelings can overshadow any learning done, by overwhelming the available working memory capacity of a learner. As the complexity, ease of use and learnability of the story map were all rated as good, it can be said that the above-mentioned negative feelings participants may have felt were limited.

Participants scored item 1 excellently, according to the Bangor et al. (2008) adjective rating scale, which focused on how frequently the participant would like to use the story map. As most participants had no prior experience with story maps (Figure 33) or the topic of the story map, the result was interesting and encouraging. As most of the participants gain no benefits academically from learning about Seoke and the Bangwaketse, the expression that they would use the story map frequently must have another reason. Perhaps the participants saw the value of the story map as a source of educational material or found that they enjoyed how the educational material was laid out. Alternatively, participants may have gained interest in the topic of southern African pre-colonial history through evaluating the story map and would like to learn more in their own time.

As the aim of the study was to create an exploratory environment for learning, the story map was developed to present information in various engaging and stimulating ways. The story map contained textual, visual and archival information. As a consequence, it was imperative to consolidate all of the different components of the story map into one coherent product. Item 5 for integration performed excellently according to the Bangor et al. (2008) adjective rating scale, scoring the highest of all of the items, with a B grade (Lewis & Sauro, 2016).

The items that performed below average describe characteristics such as technical support needed (Item 4), inconsistency (Item 6), cumbersomeness (Item 8), user confidence (Item 9) and prior knowledge needed (Item 10). Despite the below-average ratings, consistency, cumbersomeness and user confidence had a good performance and correlated to the average SUS score of the story map. Items 4 and 10 performed the worst of all of the items, scoring an F grade according to the curved grading scale (Sauro et al., 2016). This may be a symptom of the niche nature of the subject covered by the story map. As items 4 and 10 rate the required technical support and prior knowledge needed to navigate the story map, it can be inferred that the story map is not as catered to a general audience as it could be.

5.3.1.3 Overall SUS Scores for Participant Groups

As previously mentioned, the average SUS score and the item level rating averages cannot definitively determine the underlying reasons behind the participants' ratings of the story map's usability. As such, individual SUS scores were calculated for 24 groups within the participant population to indicate the demographics for which the story map is better catered. The calculated average SUS scores, in descending order, for the groups within the participants can be seen in Table 11. Of the groups, participants who were postgraduate students, enrolled in a related course, had sufficient sleep the night before, are comfortable with English and computers, had more than a casual interest in pre-colonial southern African history and had practical experience with story maps, 3D models and Google

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Earth, scored the usability of the story map higher than 65, the average SUS score for the entire population. As a note, a question regarding practical experience with Google Earth was asked as a benchmark of the participants' experience with interactive web maps and aerial imagery, considering that Google Earth is a popular and commonly used application in this regard. Furthermore, participants who had practical experience with story maps and those enrolled in a related course rated the usability of the story map the highest, with a score of 74.0 and 72.0 respectively. Regardless of country of university attendance, completion of modules related to the story map or level of knowledge of pre-colonial southern African settlements, the average SUS score was similar to the population average.

Comparatively, participants who were undergraduate students, first-year students, enrolled in an unrelated course, had insufficient sleep the night before, are not comfortable with English and computers, had a lack of interest in pre-colonial southern African history and had no practical experience with story maps, 3D models and Google Earth, scored the usability of the story map lower than the overall population SUS score. The SUS score for the first year groups was calculated separately as first-year students made up a large proportion of participants. Also, at the time that the survey was conducted, first-year students would have been in their first-ever semester at university, meaning that they would not yet have completed any university modules. However, the SUS score for the first year group was not quite different than that of the undergraduate group, with scores of 61.7 and 62.1 respectively. Participants who had no practical experience with Google Earth and who are not comfortable with English or with using a computer, scored the usability of the story map the lowest, with an average SUS score of 57.8, 52.7 and 57.9, respectively.

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Table 11. Calculated Average SUS Scores for Various Groups of Students in Descending Order

Group	Description	(n)	Overall SUS Score (Brooke, 1996)
Practical experience with story maps	Have created or used (read or studies) a story map before	17	74.0
Enrolment in a related academic course	Enrolled in a geography, GIS, remote sensing, archaeology, history or environmental science course	19	72.0
Postgraduate Students	Fourth-year*, honours, masters and PhD students.	38	71.8
Practical experience with 3D models	Have used or created 3D models in the past	32	70.2
Practical experience with Google Earth	Have used Google Earth in the past	73	69.5
Comfort with English	Comfortable or very comfortable with English	90	68.5
Interest in pre-colonial southern African history	More than a casual interest in pre-colonial southern African history	82	67.7
Sufficient Sleep	Five hours or more of sleep	71	67.5
Comfort with computers	Comfortable or very comfortable with computers	90	67.3
No completion of a related module	Have not completed a module at university covering subjects related to the story map's content	72	65.6
Minimal level of knowledge of the general topic of the story map	Little to no prior knowledge of pre-colonial southern African settlements	52	65.6
Attending a South African university	University of Pretoria and University of Witwatersrand students	98	65.5
Some level of knowledge of the general topic of the story map	Moderate to a great deal of knowledge of pre-colonial southern African Settlements	59	65.4
Attending a Botswana university	University of Botswana Students	13	65.4
Completion of a related module	Completion of a module at university covering subjects related to the story map's content	39	65.4
Enrolment in an unrelated academic course	Not enrolled in a geography, GIS, remote sensing, archaeology, history or environmental science course	92	64.2
No practical experience with story maps	Have no experience or have only heard about story maps	94	64.0
No practical experience with 3D models	Have no experience or have only heard about 3D models	79	63.4
Undergraduate Students	First, second and third years	73	62.1
First-Year Students	First-year students, who at the time, would have been in their 1st ever semester of university	52	61.7
Insufficient Sleep	Five hours or less of sleep the previous night	40	61.9
Lack of interest in pre-colonial southern African history	No interest in pre-colonial southern African history or interest limited to the duration of the survey	29	59.3
Discomfort with computers	Neutral, uncomfortable or very uncomfortable with computers	21	57.9
No practical experience with Google Earth	Have no experience or have only heard about Google Earth	38	57.8
Discomfort with English	Neutral, uncomfortable or very uncomfortable with English	21	52.7

Note: Green = better than population average SUS of 65; Yellow = similar to the population average SUS of 65; Red = worse than the population average SUS of 65

**Larger research projects are often part of the fourth year of studies. As such, fourth-year students were grouped in this category*

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For the three groups that scored the lowest average SUS score, the corresponding SUS score calculated from the item level rating averages were evaluated. The focus for this was the average item level rating for technical support and prior knowledge needed, which was identified as the poorest performing items for the population average (Table 10). As seen in Table 12, technical support and prior knowledge needed performed very poorly, particularly for participants who are not comfortable with English. The item rating averages correspond to a SUS score of 10.3 and 28.0 respectively, which, according to the Bangor et al. Adjective Rating scale, can be interpreted as scores that are the *'Worst Imaginable'* and *'Poor'*, respectively. Similar interpretations can be made for participants who are not comfortable with using a computer and who have no practical experience with Google Earth.

Table 12: Item Level Usability Evaluation of Technical Support and Prior Knowledge Needed for Participant Groups with the Lowest Average SUS Scores

	Discomfort with English (n = 21)		Discomfort with computers (n = 21)		No practical experience with Google Earth (n=38)	
Item Description	**Item Average Score (Lewis & Sauro, 2018)**	**Calculated SUS Score Corresponding to the Item Average (Lewis & Sauro, 2018)**	**Item Average Score (Lewis & Sauro, 2018)**	**Calculated SUS Score Corresponding to the Item Average (Lewis & Sauro, 2018)**	**Item Average Score (Lewis & Sauro, 2018)**	**Calculated SUS Score Corresponding to the Item Average (Lewis & Sauro, 2018)**
4. Technical support	3.48	10.3	3.19	20.4	3.13	22.5
10. Prior knowledge needed	3.57	28.0	3.19	38.3	3.18	38.5

5.3.2 Information Retention and Confidence

A critical indicator of the usability of an educational platform is whether learners learned while using it (Van Nuland et al., 2017). To evaluate this, a short test of 6 questions was included in the questionnaire to determine if participants learned. In addition to completing the test, participants were also asked to evaluate their confidence in the answers provided. The questions were based on the 3D visualizations and focused on the physicality and the spatial orientation of Seoke. Participants were asked to identify objects in the 3D visualization or to identify where an object should be placed in a scene. Four of the questions (questions 1, 2, 3 and 6) were based on models or scenes that participants would have seen in the story map. Two of the questions (questions 4 and 5) required critical thinking and the application of information available in the story map.

As seen in Table 13, participants performed very well in the test, with the average proportion of participants with correct answers being 72.86% [Kurtosis = 0.8; Skewedness = - 0.51]. The average confidence percentage was calculated to be 69.16% [Kurtosis = 0.63; Skewedness = 0.81]. There is a strong positive correlation between the proportion of participants who answered the questions

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correctly and average confidence, with a Pearson correlation coefficient value of 0.7 and a Spearman correlation coefficient of 0.75. The goodness of fit for the regression model is moderate with an R^2 value of 0.5.

Table 13. Percentage of Correct Answers and the Average Confidence Level of Participants

Question	The proportion of Participants with Correct Answers	Average Confidence	Standard Deviation for Percentage Confidence	Variance for Percentage Confidence
1. Where was waste/refuse disposed?	86.49%	66.35%	31.45	989
2. What was used to store produce or grain?	73.87%	72.68%	30.81	949.12
3. Identify the dwelling that is most like what you saw in the model.	67.57%	63.31%	30.31	918.92
4. Which of the following words best describe the objects in this image? ** (choose one or more)*	Stone Walls - 69.37% Dwelling - 72.07% Cattle Kraal - 78.38% Grain Bin - 58.56 %	70.32%	26.91	724.59
5. In this image, where could a dwelling have been located? **(choose one or more)*	49.55%	62.28%	28.34	803.10
6. In this image, where would livestock (cattle, goats or sheep) be kept?	90.09%	80.04%	26.17	685.10
Average	**72.86%**	**69.16%**		
Kurtosis	**0.80**	**0.63**		
Skewness	**-0.51**	**0.81**		

Regarding confidence in the answers provided, the largest proportion of the participants rated their confidence in the 80% - 100% bracket (Figure 37) for each of the questions. However, the variance in the confidence percentage data set is quite large. Considering the below-average item level SUS score for confidence (item 9) in using the story map (Table 10), participants for the most part did not lack confidence in their answers for the test. Even in cases where approximately half of the participants got the answer wrong (question 5), participants were still relatively confident.

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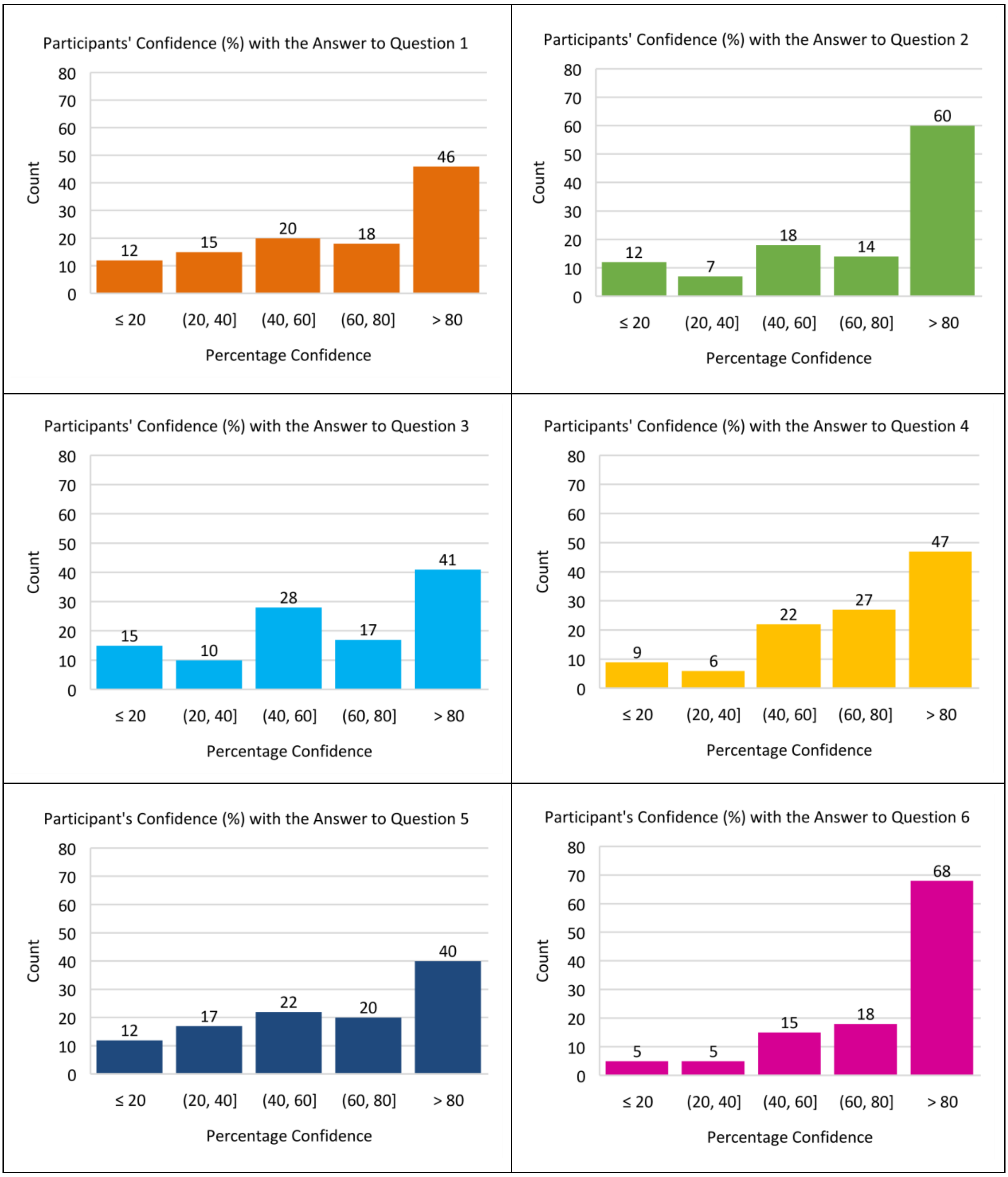

Figure 37. Histograms of Participants' Confidence in Question Answers

As a further evaluation, the point biserial correlation coefficient was calculated to determine the correlation between the self-rated confidence scores of participants who answered questions correctly versus those of those who answered incorrectly (Equation 2). A biserial correlation coefficient is a specific case of a Pearson's correlation coefficient (LeBlanc & Cox, 2017; Glen, 2016), used to determine the relationship between one continuous (in this case the participants' self-rated confidence percentage) and one binary variable (whether the participant answered correctly or incorrectly).

Equation 2. Point Biserial Correlation Coefficient (Glen, 2016)

$$r_{pb} = \frac{M_1 - M_0}{S_n} \times \sqrt{pq}$$

Where:

M_1 = Mean of positive binary variable 1
M_0 = Mean of negative binary variable 0
S_n = Standard deviation of the entire test
p = Proportion of cases in the 0-variable group
q = Proportion of cases in the 1-variable group

The sample for participants who answered correctly was selected for participants who scored 100% for a question. In this regard, for question 4 where there were four possible answers, participants who got all 4 answers correct were selected for the sample. The point biserial correlation coefficient values can be seen in Table 14. The values fall between 0.25 and 0.36, which shows a weak positive relationship between 100% answer accuracy and confidence.

Table 14. Correlation Between Participants' Answer Accuracy and Self-rated Confidence Percentage

	100% Accurate			Not 100% Accurate			
Question	**Sample Size (n)**	**Average Confidence**	**Sample Variance for Confidence**	**Sample Size (n)**	**Average Confidence**	**Sample Variance for Confidence**	**Point Biserial Correlation Coefficient (r_{pb})**
1	96	69.81	895.27	15	40.00	1158.46	0.28
2	82	77.26	840.71	29	59.52	1089.76	0.25
3	75	70.35	762.33	36	48.83	983.63	0.33
4	42	79.60	533.56	67	64.67	775.52	0.27
5	55	70.45	758.58	56	54.25	729.75	0.29
6	100	83.19	545.45	11	51.36	1200.85	0.36

As discussed above, regardless of the below-average performance of the SUS item level score for confidence (item 9), participants did not lack confidence in their answers for the test. The correlation between the self-rated confidence scores of participants who answered questions 100% correctly and those who did not, is positive, but minimal. However, the variance for self-rated confidence between those who answered the questions 100% correctly is in all cases smaller than for those who did not answer 100% correctly. Similarly, average self-rated confidence for participants who got the answers 100% correct is higher in all cases than for those who did not get the answers 100% correct.

Besides the results of the short test as an indicator of if participants learned, participants were also asked to report if they felt that they had learned (Figure 38). Participants were asked if the experience of reading through and interacting with the story map was enlightening, as the phrase conveys a meaning of knowledge and understanding gained. About 98% of participants reported that the experience was enlightening to some degree. About 65% of respondents reported that they experienced a lot or a great deal of enlightenment.

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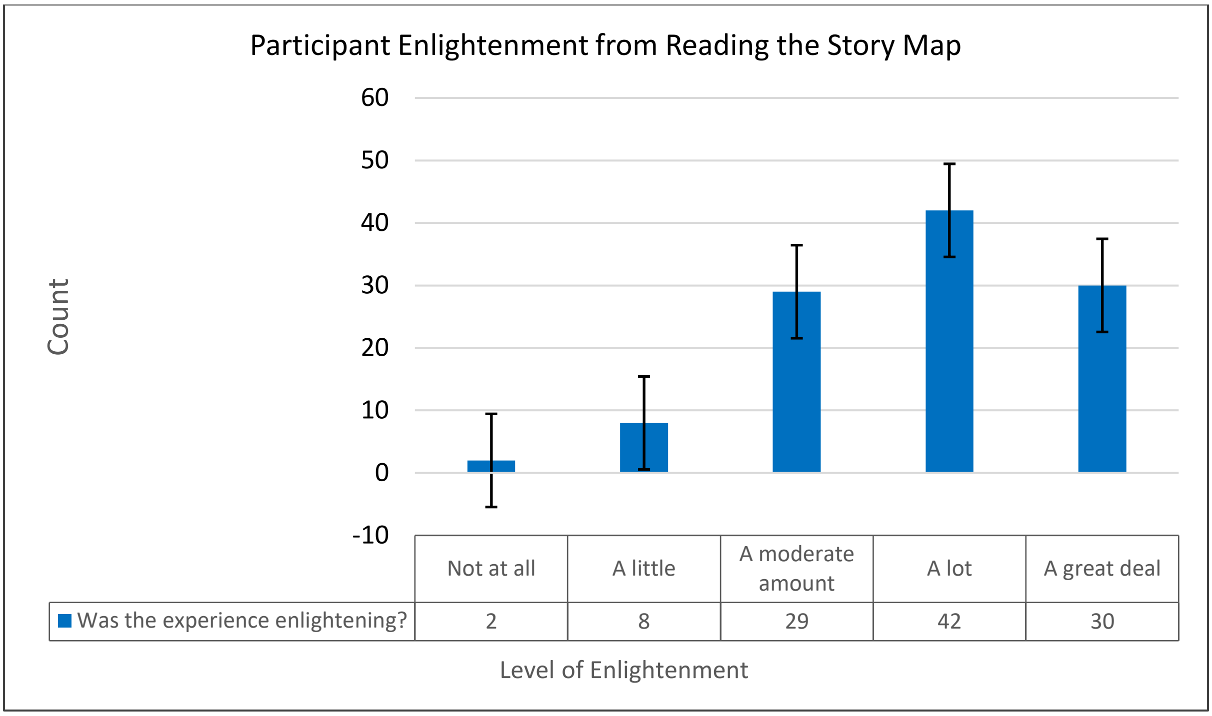

Figure 38. Participants' Enlightenment Experienced from the Story Map

5.3.3 Value and Perception

The pedagogical value of the story map and 3D visualization as a digital exploratory environment was evaluated by the participants. The questions answered were influenced by the problem statement, aims and objectives of the study, which were to create an exploratory environment for learning, considering the limitations in Seoke's accessibility. Regarding value, three questions were asked about the 3D visualization and two were asked about the story map. Overall, participants responded positively (Figure 39).

Participants mostly agreed or strongly agreed that the 3D models were a complement that helped in the understanding of the textual information. Similarly, participants mostly agreed or strongly agreed that the 3D visualization helped them to imagine Seoke. As access to the site is limited for several reasons (Section 1.2), it was valuable to provide learners with some sense of Seoke's physicality. As such, this response was quite good. Again, participants agreed or strongly agreed that the 3D visualization made learning about Seoke more engaging. However, this was not by as great of a margin as the prior two statements, as several participants were neutral.

Approximately half of the participants strongly agreed that the story map was an innovative way to learn about Seoke. Lastly, most participants agreed or strongly agreed that virtual field trips for cultural heritage sites such as Seoke are valuable. As discussed in Section 5.3, participants excellently rated the SUS item regarding how frequently they would like to use the story map. This was assumed to be as a result of the participants discovering the value of the story map as an educational tool or new interest in pre-colonial southern African history, as the participants gained no academic benefits from learning about Seoke and the Bangwaketse. Consequently, the response to the statement regarding the value of virtual field trips for cultural heritage sites such as Seoke makes the inference of the reasoning for the response to the SUS item even more likely.

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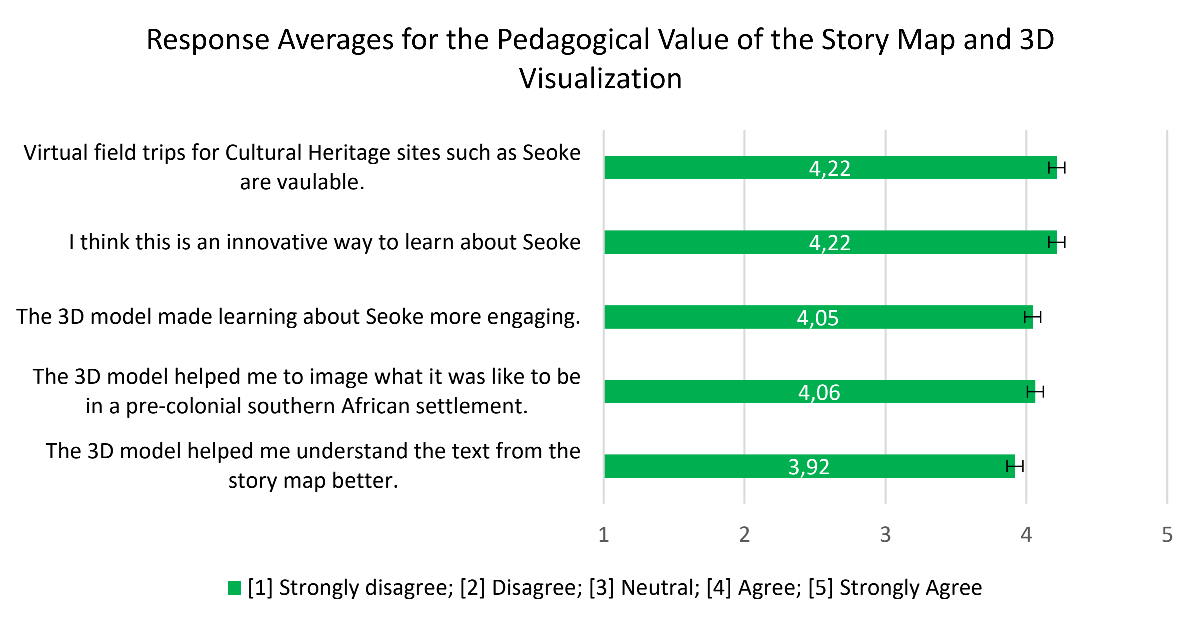
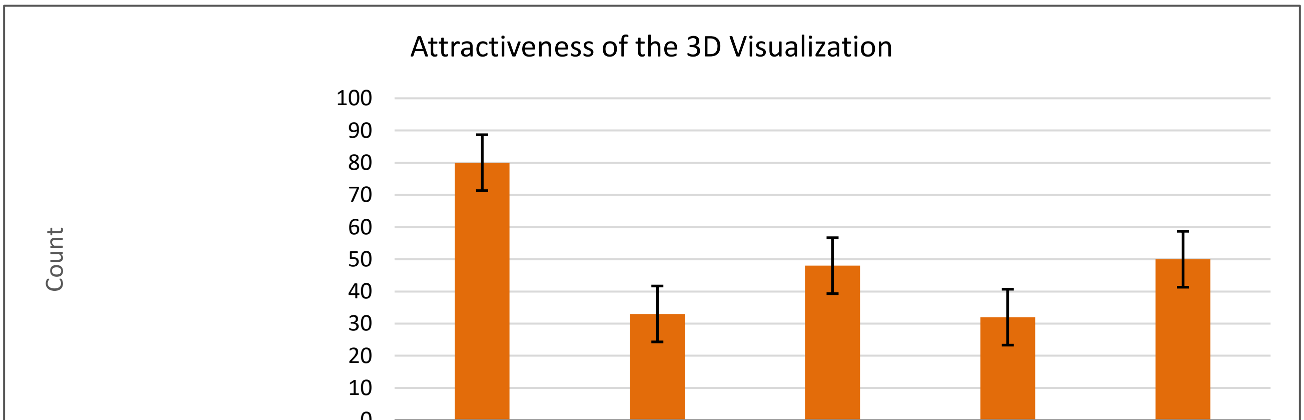


Figure 39. Pedagogical Value of the Story Map and 3D Visualization

The 3D models and scenes, designed for functional realism (see Sections 2.2.4, 3.1.2 & 3.2.3), were built clean and geometrically due to the nature of the software. CityEngine is primarily catered to modelling modern, urban cityscapes. Consequently, there was a concern that the models would appear too inorganic or unrealistic and take away from the immersiveness of the 3D visualization. Participants were asked to evaluate the 3D visualization, by selecting one or more characteristics that describe what made the 3D visualization or scene attractive (Figure 40). Graphics and realism received the highest number of responses, with interactiveness and ease of navigation performing similarly.



	Graphics and realism	It was something new	Easy to navigate	It was different from other visualizations I have seen in the past	Interactiveness
What made the 3D visualization attractive	80	33	48	32	50

Figure 40. Qualities that Made the 3D Visualization Attractive to Participants

To understand how the 3D models were perceived, participants were also asked how organic or realistic they viewed the 3D models to be (Figure 41). Most participants responded quite favourably.

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The highest number of responses selected *a lot* and *moderate* as a descriptor for the organicness and realism of the models. With the combination of the responses regarding the attractiveness of the 3D visualization (Figure 40) and participants' perceptions of it, (Figure 41), it can be said that the geometric appearance of the 3D models did not detract from its attractiveness and that the models appeared more realistic to the participants than expected.

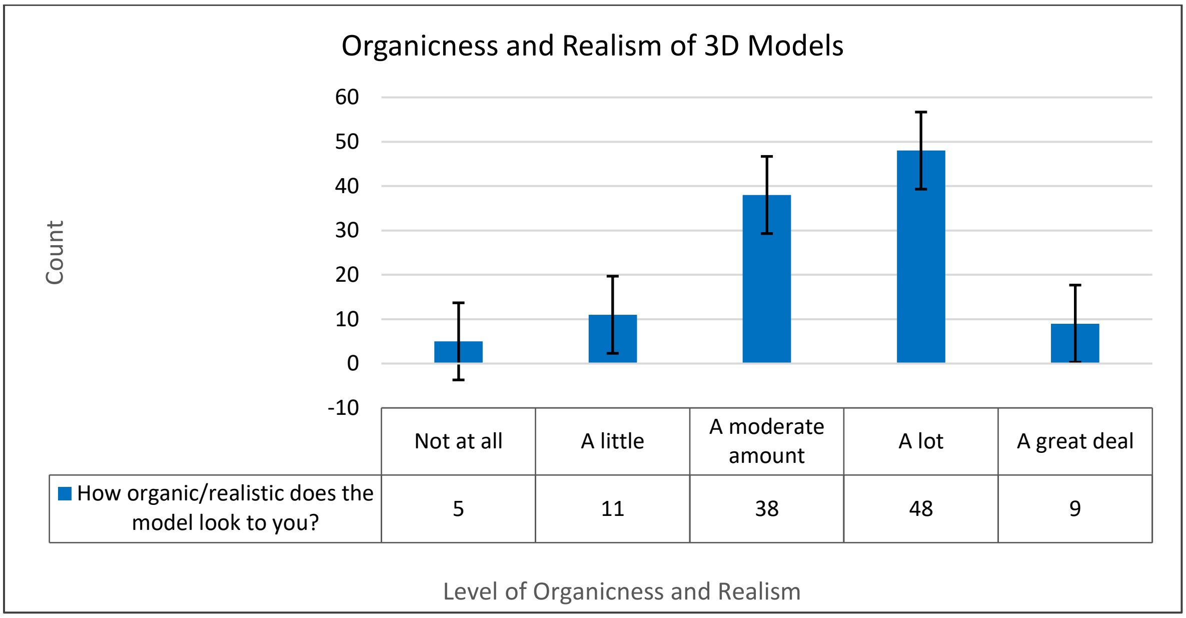

Figure 41. Participants' Perceptions of the Organicness and Realism of the 3D Models

Lastly, participants were asked questions about their perception of Seoke and pre-colonial southern Africa. As this study was conducted with students from southern African universities, it was likely that some of the participants may have personal experience with settlements similar to Seoke, likely in part due to their background or heritage. As seen in Figure 42, about 91% of participants reported that Seoke resembled a settlement that they have visited or lived in, to some degree. However, participants mostly reported that there was little to moderate resemblance.

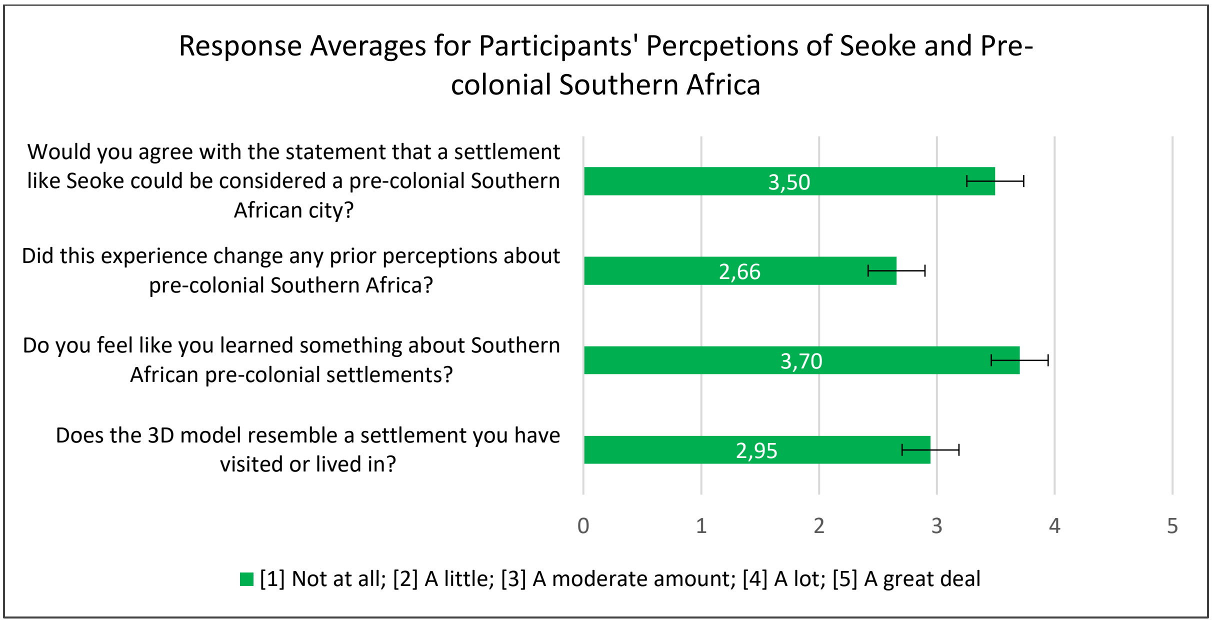

Figure 42. Participant's Perceptions of Seoke and Pre-colonial Southern Africa

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As most of the participants reported that they had some experience with settlements similar to Seoke, it can be assumed that the participants have perceptions about similar settlements. Consequently, participants were asked if the story map changed their perceptions about pre-colonial southern Africa. 83% of participants reported that the story map changed their perception of pre-colonial southern Africa in some way, with most reporting that there was little to moderate change in perception. Participants were also asked about their views on considering Seoke as a pre-colonial southern African '*city*'. As the mainstream measures of urbanism are based on Eurocentric standards (Section 2.1), settlements like Seoke are often dismissed as not urban. The story map actively presented Seoke to the reader based on the indicators of urbanism in African settlements. 97% of participants agreed to some extent that Seoke can be considered a '*city*', with most of the responses agreeing with the statement a moderate amount or a lot.

5.4 Discussion

Overall, the usability survey analysed the usability of the story map as an exploratory digital environment for learning by evaluating the various components that contribute to the effectiveness, efficiency and satisfaction of the platform. As a standard approach, the usability of the story map was evaluated using the System Usability Scale (SUS). The SUS, developed by Brooke, is a usability testing tool for industrial systems. The SUS was designed to determine participants' subjective perceptions about the usability of a system, keeping effectiveness, efficiency and satisfaction in mind. (Brooke, 2013). From the responses of all of the participants, the story map performed just below average according to the Sauro et al. (2016) curved grading scale, with a score of 65, which translates to a C grade. Alternatively, by using the Bangor et al. adjective rating scale (2008), the usability of the story map can be described as *'Good'*. Overall, the story map as a platform did not have exceptional performance, however, it did not fail either. The average SUS score showed that the story map would benefit from improvements at the system level. As this research was a case study for a project with plans to expand, this is valuable information.

The overall SUS score of 65 is a broad descriptor of the system-level usability of the story map, with no further reasoning for why participant feedback resulted in a SUS score that can be interpreted as *Good*. To assess system-level usability in finer detail, the item level averages for the SUS questionnaire were evaluated. Each item (question) in the SUS questionnaire is targeted at qualities of system usability – item 2 targets complexity and item 7 targets learnability, for example. To identify which qualities of the story map performed well, and which qualities require improvement, the item level ratings and the SUS scores that correlate to those ratings were assessed.

At the item level, items targeting ease of use, learnability, complexity, integration and frequency of use performed above average. Regarding the components of usability, the ease of use, learnability and complexity of a platform are attributes that contribute to the efficiency of the platform. Efficiency is a measure of the amount of effort and resources that users need to complete a task while using a platform. In the case of an educational platform such as the story map, the task users need to complete is learning. If a platform is easy to use, easy to learn to use and has the right level of complexity, the effort needed to learn is minimised (Van Nuland et al., 2017; Jardodzka et al., 2017). Additionally, a well-integrated platform contributes to the effectiveness of a platform. An effective platform supports the user in completing tasks. A well-integrated platform combines different

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components into one concise product and presents various resources that support the user in learning. Furthermore, a platform that users would like to frequently use means that the platform is satisfactory to use. Users must feel comfortable while using a platform to feel satisfied and, in this case, users are comfortable enough with the story map to want to use it again (Brooke, 2013).

Amongst all of the items, those targeting frequency of use and integration performed the best. As such, it can be said that the story map is more effective and satisfying to use, moreso than the story map being efficient to use. The three components of usability - effectiveness, efficiency and satisfaction - must work in tandem to boost each other. Improving the efficiency of the story map by reducing the effort needed to learn will help to improve the average SUS score. In doing so, readers will be able to learn while expending minimal effort, which in turn will allow readers to learn more using the same amount of effort and increase their comfort while learning.

Of the items that performed the worst, items targeting the required technical support and prior knowledge needed to navigate the story map received the lowest scores. The SUS scores that correlate to these item rating averages fall within the F grade for the curved rating scale (Sauro et al., 2016). The item rating averages clearly show that the story map needs to improve regarding these attributes. The poor scores regarding required technical support and prior knowledge needed to navigate the story map show that participants were likely intimidated by the technicality of story map or felt that the story map assumed a baseline of prior knowledge from users.

To investigate further, the SUS questionnaire data was split into 24 groups for which average SUS scores were calculated. The average SUS score and the item rating averages cannot definitively indicate the underlying reasons behind the participants' evaluation of the story map's usability. However, calculating the average SUS scores for groups within the population can indicate the types of demographics for which the story map is better catered. Of the 24 groups, 15 scored the usability of the story map better than or the same as the population average. Participants who had practical experience with story maps, those who were enrolled in a related course and those who were postgraduate students scored the usability of the story map the highest. These three groups of participants encompass those with more academic experience than the rest of the participants. Considering the other groups that scored the usability of the story map higher than the population average (comfort with English or using computers, sufficient sleep and practical experience with story maps, 3D models or Google Earth), it appears that comfort and familiarity are common demographic characteristics.

Nine groups scored the usability of the story map lower than the population average. Of these, participants who were not comfortable with English, not comfortable with using a computer and those who had no practical experience with Google Earth, scored the story map's usability the lowest. Participants within these three groups also scored the SUS items for technical support and prior knowledge needed very poorly. It cannot be said that discomfort with English and computers and the lack of practical experience with Google Earth are the definitive underlying reasons for the poor performance at the item level for technical support and prior knowledge needed. It can, however, be inferred that participants who are uncomfortable with English, uncomfortable with using computers and have no practical experience with Google Earth, strongly think that they would need the support of a technical person and would need to learn a lot of things to use the story map. It can also be

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inferred that the actual technical support and prior knowledge needed to use the story map may be related to the language or jargon used in the story map or the technical computer skills needed to use and understand story map, considering that practical experience with Google Earth was used as a benchmark for experience with web maps.

The SUS is a system-level evaluation of usability and thus cannot indicate how users learned while using the story map. The SUS questionnaire moreso highlights system qualities of the story map that may improve or impede learning. Adding to the three components of usability - effectiveness, efficiency and satisfaction - ultimately, the major factor of usability for an educational platform is if users can learn while using it (Kortum & Peres, 2014; Van Nuland et al., 2017). To assess this, participants were given a test about the physicality and spatial arrangement of Seoke, with reference to the 3D visualizations in the story map. Participants were also asked to rate their confidence in the answers provided from 0% to 100% confidence. Overall, the average proportion of participants with correct answers was approximately 73%. The participants' average self-rated confidence for their answers was 69%, however, the self-rated confidence data had high variance. For each question in the test, the 80% - 100% self-rated confidence range received the highest proportion of responses from participants. Although system-level issues with the story map were identified through the SUS (i.e., technical support and prior knowledge needed), the effect on learning done by users was not detrimental. Based on the average scores for the short test that participants completed, the content of the story map was conducive to learning although the story map, as a system, needs work. However, the fact that participants performed well in the test despite the issues identified in the SUS evaluation indicates that the story map is functional as a product based on the aims and objectives of this study, which was to develop a digital environment for learning.

There was a strong positive correlation between the proportion of participants with correct answers and average confidence, with a correlation coefficient of 0.7. However, the correlation between the confidence scores of participants who answered the questions 100% correctly, versus those who did not, was positive but weak, ranging between 0.25 and 0.36 for all of the test questions. Participants who did not answer the questions 100% correctly did, on average, self-rate their confidence lower than those who answered correctly.

In summary, it can be said that the number of participants who answered the questions correctly increased, the higher the average confidence in answers were. However, participant's self-rated confidence is not strongly correlated to whether they were wrong or right in their answers. This is quite an encouraging finding when evaluating an educational platform. Confidence while learning is indicative of a learner's expectation of positive results after exerting effort to learn (Moller, 1993). Moreover, confidence has been found to reflect positive emotional, cognitive and performance effects in learners (Norman & Hyland, 2003). Participants' self-rated confidence not being strongly correlated to their accuracy, shows that participants were motivated to learn and expected positive results from what they learned. Negative feelings such as anxiety or frustration, which can be a result of lack of confidence, can lead to avoidance attitudes, a reduction in time spent learning and a decrease in how much of what was learned being processed (Kremer et al., 2019). The evaluation of self-rated confidence shows that the educational material presented in the story map does not impede on learner's confidence and can facilitate learning from the perspective of learner confidence. Consequently, when asked if the story map was enlightening, 98% of the participants reported that the story map was enlightening to some degree. The participants' performed quite well regarding

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information retention and the application of knowledge gained, and self-reported that they had learned. Participants responded quite positively to questions regarding the pedagogical value of the story. Approximately 79% of the participants agreed to some degree that virtual field trips for cultural heritage sites were valuable and 76% of participants agreed to some degree that the story map was an innovative way to learn about Seoke.

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Chapter 6: Eye-tracking Study

This chapter discusses the eye-tracking study conducted for the story map. The overview section lists the various reasons for which certain components of the story map were analysed using the eye tracker and the potential knowledge that can be gained from it. The materials section covers the equipment and software used, whereby the procedure section presents the routine of the study and the questionnaire that participants filled out. The results and evaluation section reports on the findings of the eye-tracking study using gaze-fixation heatmaps and graphical visualizations. Lastly, the discussion section elaborates on the findings of the study and the knowledge gained from it.

6.1 Overview

Eye-tracking is a psychophysiological approach to usability testing that assumes a link between mental and visual attention patterns (Wang et al., 2019). Where Chapter 5 evaluated the system-level usability of the story map as a digital exploratory environment for learning, the purpose of the eye-tracking study is to provide insight into user focus and attention (Wang et al., 2019) while using the story map interface. Beyond user focus and attention, eye tracking can also provide insight into the learning process. The learning process can be affected by working memory capacity overload, which can occur when instructional material is laid out ineffectively (Jardozka et al., 2017). By assuming a link between the eyes and the mind, the eye-tracking study aimed to identify the content that drew the attention and the visual search of readers when asked to complete certain tasks.

6.1.1 Outline

How readers of the story map use and look at the content and functionalities of the story map was analysed using eye-tracking technology. In this regard, the following categories of assessment were outlined:

i) Distribution of Attention Across the Text and Media: Firstly, identify the distribution of attention across the textual information and the media presented by the story map, especially when the media carries important information, such as in the case of maps or images of the actual site.

ii) Completion of a Task in the Archive: Secondly, the eye-tracking study should analyse how participants search for information when prompted with a task. Using gaze path videos, patterns of behaviour depicting where participants assumed information should be, must be determined. The gaze path videos must also be utilised to calculate the average time it took for participants to complete the task.

iii) Visual and Auditory Focus Level: Additionally, participant attention and engagement should be identified using gaze-path videos for when participants watched the video about the Northern cluster of Seoke. For every section of the video, the degree of agreement between visual attention patterns and the subjects of the voice over must be determined. In addition, fixations on random points of the video should be highlighted as an indicator of boredom or 'zoning out'.

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iv) Interactivity: Lastly, the extent to which participants engage with the story map and perform actions that break apart from the linear flow of the story map should be identified.

6.2 Materials

The eye-tracking study was conducted from the 30th of March to the 1st of April 2021 at the University of Pretoria's eye-tracking lab in the Department of Informatics. The study was structured and performed under the supervision of Kalley Coleman, the coordinator of the University of Pretoria's UX labs.

6.2.1 Equipment

The Tobii X3-120 eye tracker, which has a 120Hz refresh rate, was used for this study. The presentation screen that was used by participants was an LG IPS FULLHD monitor with a resolution of 1920x1080.

6.2.2 Software

Tobii Pro Lab v1.162 Full Version was used to conduct the study, analyse the data and create visualizations of the data. When generating the gaze-fixation heatmaps and gaze-plots, a similarity threshold of 50% was used, which is the default for the software. This threshold level accommodates for the scrolling or movement that may have occurred while participants were reading the story map. As the eye-tracking footage overlaid the gaze fixation points on a snapshot image of a section, a match between the footage and the image was necessary. For one participant, the similarity threshold was set to 81% due to some data loss. This means that the software was more stringent in plotting points as a gaze fixation in this one case.

6.3 Procedure

The study was conducted one-on-one as the participants were asked to book a participation timeslot ahead of time. Participants of the eye-tracking study did not participate in the usability survey (Chapter 5). They had no exposure to the story map before participating in the eye-tracking study. The eye-tracking study was performed during the daytime in a large room that received natural light in addition to the overhead artificial lights.

The study was structured into 3 distinct sections. Firstly, participants were welcomed upon arrival at the labs. Once seated, the participants were informed of the nature of their participation. Participants were told that their eye movements would be tracked while they read a story map. They were reassured that the subject of the study was the story map, not themselves and that they should not feel pressured if they encountered problems or were unsure of what to do. Additionally, it was reiterated that no personal information would be gathered or shared. After reconfirming their consent to participate in the study, the eye tracker was calibrated to the participant. Participants were instructed to keep their eyes on the screen at all times while partaking, even while asking questions or being prompted.

The eye-tracking study itself prompted participants to read through the story map freely for 5 minutes. After the first 5 minutes, participants were prompted to complete several tasks. These tasks included

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downloading Shapefiles from the archive and interacting with the dwelling 3D visualizations. Lastly, participants were asked to watch the video at the end of the story map. During the study, the number of interactions that the participant made with the story map was noted. Considered interactions include the opening of the archive and visualization buttons without prompting, opening attributions and their level of interaction with the web map.

On completion of the eye-tracking portion of the study, participants were directed to complete a short questionnaire (Annex 14). The questionnaire included demographic questions, a short test to gauge what participants learned and lastly questions about the experience and perceptions of the story map.

6.3.1 Stimuli

The story map, along with the textual information, displays various forms of media. Through the eye-tracking study, inferences of the effectiveness and attractiveness of the various forms of information can be made. Each type of media utilised in the story map will be evaluated using a representative section, mainly:

i) 2D Maps: *'Pre-colonial Southern African Settlements'* section
ii) Images: *'Stone Walls'* and *'Inhabitants of Seoke'* sections
iii) 3D Visualization: *'Dwelling Visualization'* section
iv) Video: *'Northern Cluster'* section
v) Archive: '*Visual Item: Shapefiles of Seoke stone walling'*

6.4 Results and Evaluation

6.4.1 Participants

A total of 16 students participated in the eye-tracking study. Of the 16 participants, 12 were female and 4 were male. All of the participants were in their early twenties with seven third-year students and nine Honours students (Table 15). The courses that participants were enrolled in were far less diverse than those in the usability survey. The participants were all BSc students. Participants were asked about their comfortability with the mediums used to conduct the study, namely with English (the language used in the story map and for instructional communication) and with using a computer (Figure 43). Most of the participants claimed they were comfortable or very comfortable.

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Table 15. The Gender and Ages of the Participants for the Eye Tracking Study

			Count
Gender	Female		12
	Male		4
Age	Mean		22
	Min		20
	Max		24
	Std.Dev		1,13
Academic Year	Third-year	BSc Geoinformatics - 7; Bridging - 2	9
	Fourth-year /Honours	BSc(Hons) Geoinformatics - 6; BSc(Hons) Geography and Environmental Science - 1	7

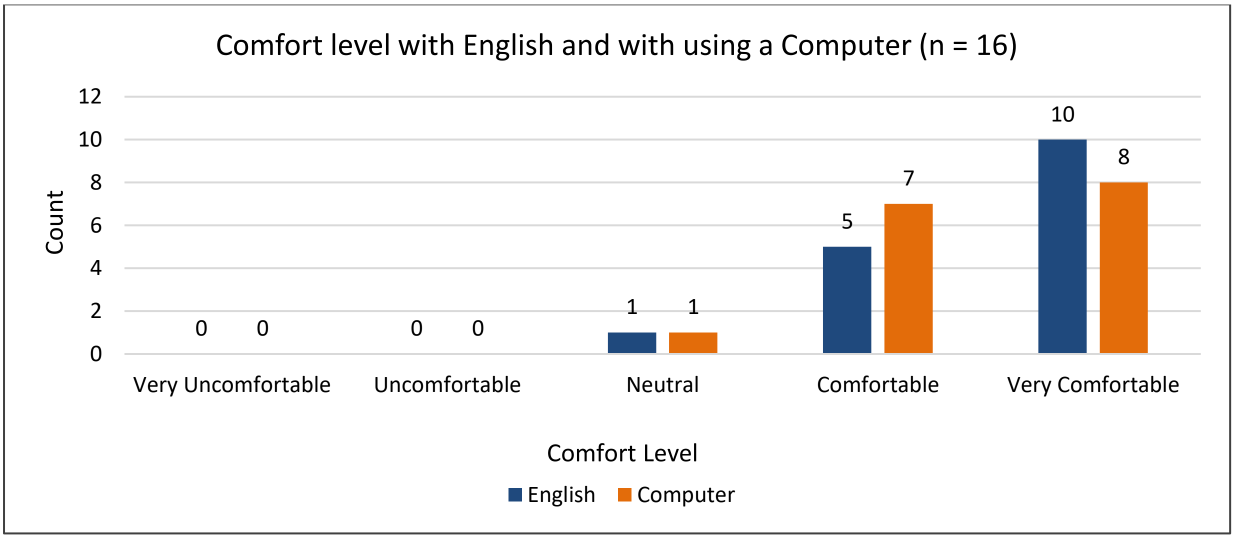

Figure 43. Participants of the Eye-tracking Study's Comfort Level with English and with using a Computer

When asked to rate their interest level in the topic of southern African Pre-colonial history, most participants rated their interest as short-term or casual (Figure 44). Furthermore, participants mostly reported that they had a little or moderate amount of prior knowledge about southern African pre-colonial settlements such as Mapungubwe or Great Zimbabwe (Figure 45).

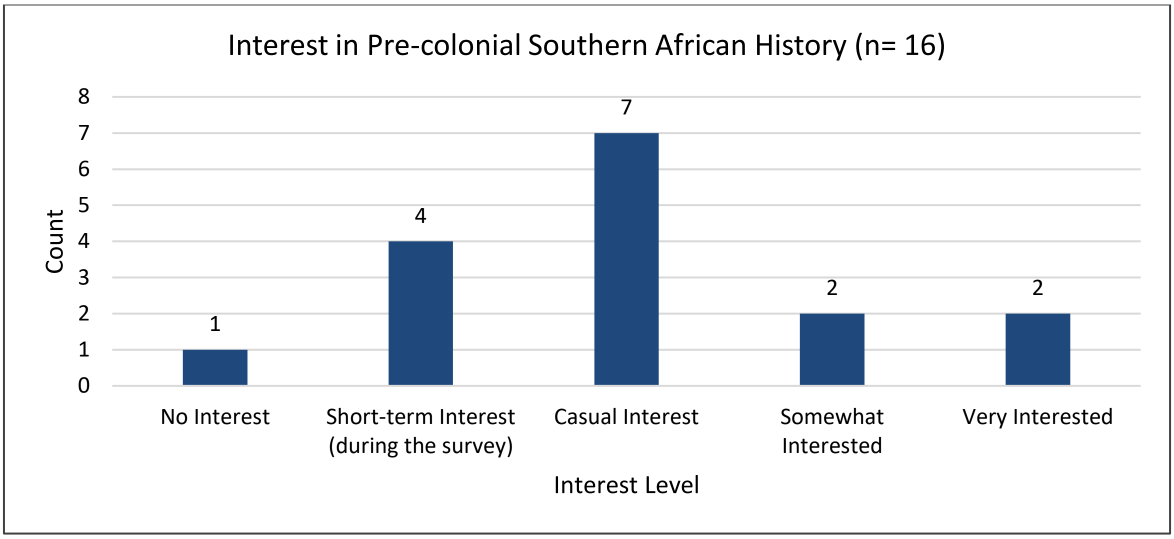

Figure 44. Participants of the Eye-tracking Study's Level of Interest in Pre-colonial Southern African History

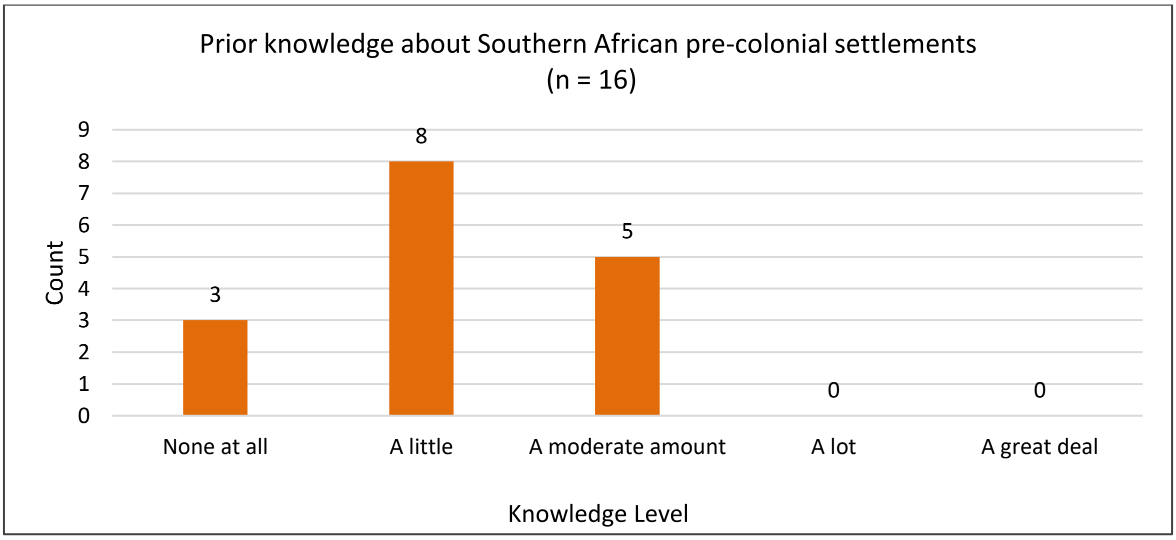

Figure 45. Participants of the Eye-tracking Study's Prior Knowledge about Southern African Pre-colonial African Settlements

6.4.1.1 Calibration

The eye tracker was calibrated to the eye movements of each participant before commencing with the study. Data loss for the calibration measured between 0% to 5% except for two cases where data loss was at 8% and 13% due to the participants being glasses-wearers. However, the data loss was still within the accepted range, as advised by the lab coordinator.

6.4.2 Distribution of Attention Across the Text and Media

6.4.2.1 2D Maps

The *'Pre-colonial Southern African Settlements'* section of the story map is information-dense. It introduces the reader to the history of the study of early settlements and urbanism, and why the study of settlements such as Seoke is important. A 2D map, the main media for this section, shows the

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distribution of the archaeological sites of pre-colonial southern African settlements with the Zimbabwean or Central Cattle Pattern (CCP) walling traditions (Section 2.1.2).

A heat map of cumulative gaze fixations was generated to illustrate participants' visual engagement with this section. The intensity of a fixation is demonstrated by colour, with green representing a lower intensity, to red, which represents high intensity. The opaqueness of the colour represents the overlap of gaze fixation data from the different participants. As seen in Figure 46, participants strongly fixated on the textual information in addition to the information presented in the 2D map. Based on the intense fixations on the legend of the map and the additional fixations on the corresponding map symbols and insert map, participants took time to fully understand all of the information presented. The educational material in this section appears to have been laid out effectively as the fixations are centred on the points of interest (text, map, map legend and insert map) of educational value.

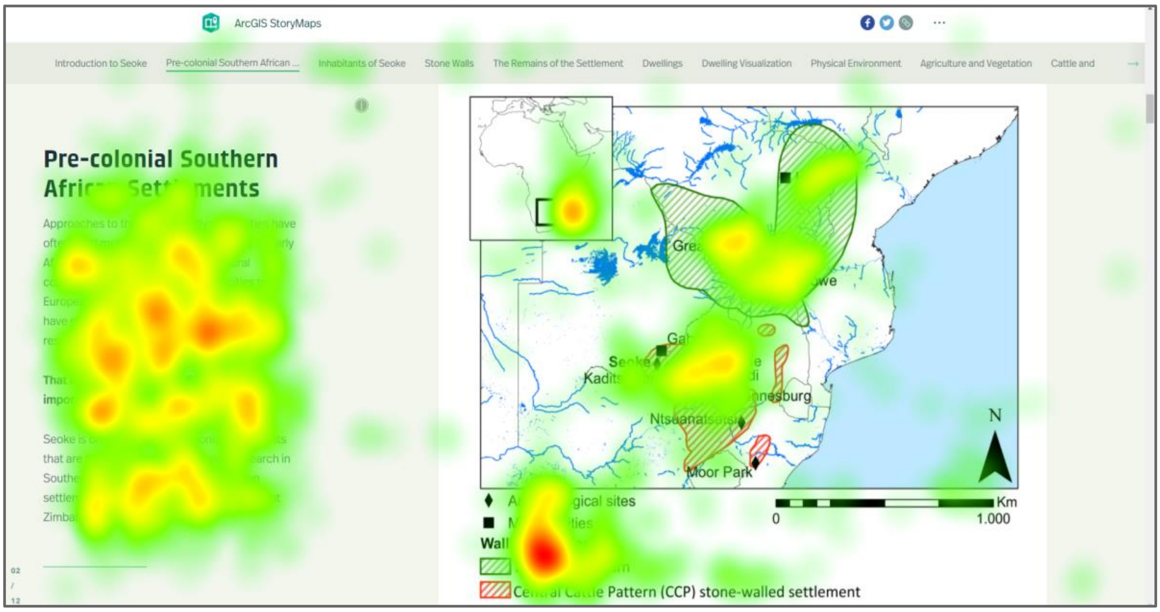

Figure 46. Overall Gaze-fixation Heatmap of the ‘Pre-colonial Southern African Settlements’ Section

In assessing the participants gaze-paths, which visualizes the succession of participants’ gaze-fixations, and as visualized in Figure 47, it was observed that 62.5% of the participants looked at the map first, whilst 37.5% of the participants looked at the text first. Comparing the participants’ focus on the textual information to the higher propensity of participants looking at the 2D map first, it can be determined that there was a balance between the text and the media overall. Considering how information-dense both the text and the 2D map are, participants, on average, did not avoid any of the educational material or focus on only one aspect of the section due to being overwhelmed. However, at the individual level, three participants only looked at one aspect of the section, with two focusing solely on the text and one focusing solely on the 2D map.

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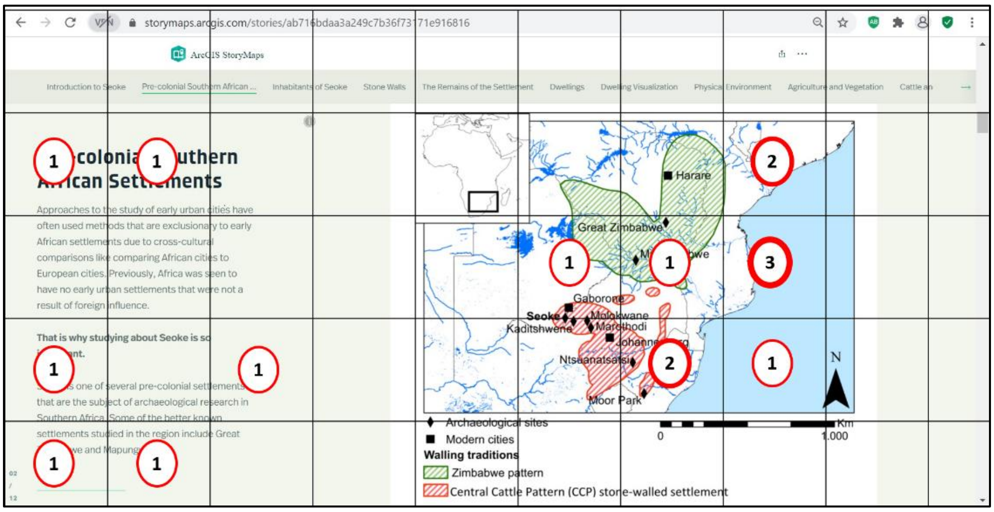

Figure 47. First Gaze Fixation Per Grid for the 'Pre-colonial Southern African Settlements' Section

6.4.2.2 Images

Contrary to the evenly distributed attention spent on the information-dense section mentioned above, the sections that featured images as the main media received a different result. The *'Stone Walls'* section introduces the reader to the most apparent archaeological remains of the Seoke settlement. Through the textual information, the participant was informed of the start of the practice of stonewalling, of the significance of stonewalling and the number of stone walls found at the site. The participant was also shown images of the stone walls at the site, which was the first close-up view of the site that is presented.

Figure 48. Overall Gaze-fixation Heat Map of the 'Stone Walls' Section

Participants focused mostly on the text and fixated very briefly on the images of the stone walls, with one participant having not fixated on the image at all. In the cumulative gaze-fixation heatmap (Figure 48), this is illustrated by the transparent green spots overlapping the collage of the stone walls. The transparent green colour indicates that fixations were brief and not intense. Comparatively, the opaque yellow to red colour overlapping the text indicates that the fixations were prolonged and intense. Participants tended to bounce very quickly to each image in the collage, instead of fixating or scanning through the images. This could perhaps be attributed to the layout of the images. The collage layout reduces the size of each image and makes it unclear as to where the participant's focus should be placed. In addition, the images of the stone walls may have lacked in impact for the participants. Although the images depict significant archaeological objects, the stone walls may appear as less significant or uninteresting when perceived by someone who is not familiar with pre-colonial southern African settlements.

The gaze fixation heat map for the *'Inhabitants of Seoke'* showed a similar result to the *'Stone Walls'* section. The *'Inhabitants of Seoke'* section is a short section that introduces the Bangwaketse to the reader and discusses their regional influence. A photograph of Ngwaketse children and women accompanied the textual information presented in this section (Figure 49). Similar to the *'Stone Walls'* section, the photograph of the children and women had no clear focal point as there are many faces in the image. Even with the difference in layout, (collage layout vs. single image) gaze fixations remained centred on the textual information more so than the image, as illustrated by the opaque yellow to red colour overlapping the text. Fixations centred on the subjects in the image were mainly centred on the faces of the individuals photographed. However, there were also many fixations on the photograph that appear to not be centred on anything in particular. The transparent green spots scattered over the photograph shows that the fixations on the image were brief and lacked intensity.

Figure 49. Overall Gaze-fixation Heat Map of the 'Inhabitants of Seoke' Section

In both cases, the lack of intense fixations on the images does not mean that the participants did not see the images. The eye tracker can detect and map gaze fixations, however, it cannot identify what the participants saw in their peripheral vision. It is likely, that the participants saw the images of the stone walls and the Ngwaketse children women in their peripheral vision while reading the textual information. However, what they saw in their peripheral vision did not attract enough attention to fixate on the images. Gaze-path maps were assessed to identify the succession of participants' gaze fixations to determine whether the images failed in attracting the attention of the participants (Figure 50; Figure 51). The gaze-path maps for the 2 above-mentioned sections found that the participants'

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first fixations for these sections were quite evenly split between the image and the text. 50% of participants looked at the text first for the *'Stone Walls'* section and 44% for the *'Inhabitants of Seoke'* section. Also, considering that only one participant per section did not fixate on the image at all, it can be determined that the images are not completely inconspicuous.

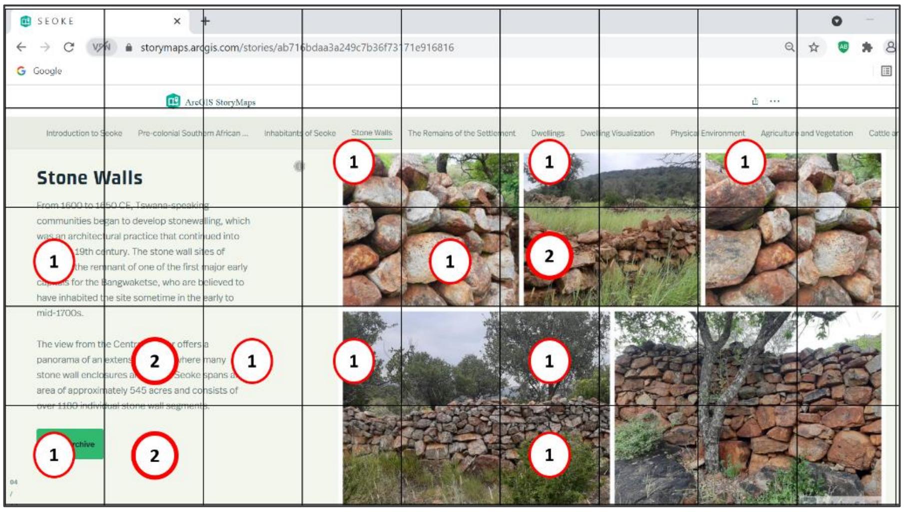

Figure 50. First Gaze Fixation per Grid of the 'Stone Walls' Section

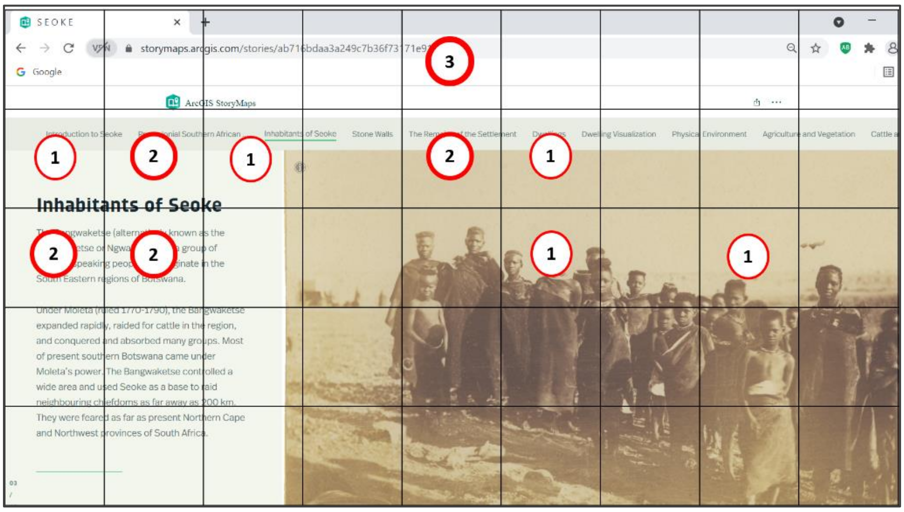

Figure 51. First Gaze Fixation per Grid of the 'Inhabitants of Seoke' Section

6.4.2.3 3D Visualizations

The dwelling visualization in the story map is a simple interactive visualization of several objects that could be found near a dwelling. The visualization is centred around a dwelling model which is enclosed within a stone wall. A grinding stone and pot are located in the courtyard and a midden is located behind the stone enclosure. Lastly, a grain bin is located to the side. Participants were prompted to look at and interact with the visualization. A heatmap was generated that mapped the gaze fixations of participants when looking at the complete scene. As seen in Figure 52, the cumulative gaze fixations were centred on the comment-callout icons rather than the objects themselves. The comment-call out icons were available for every 3D object in the scene and indicate to the user of the descriptive information available. Clicking on the comment-callout icons brings up a pop-up of information about an object. The gaze fixations at the bottom of Figure 52 were as a result of the prompt given to participants that instructed them to move between views using the thumbnails along the bottom of the screen.

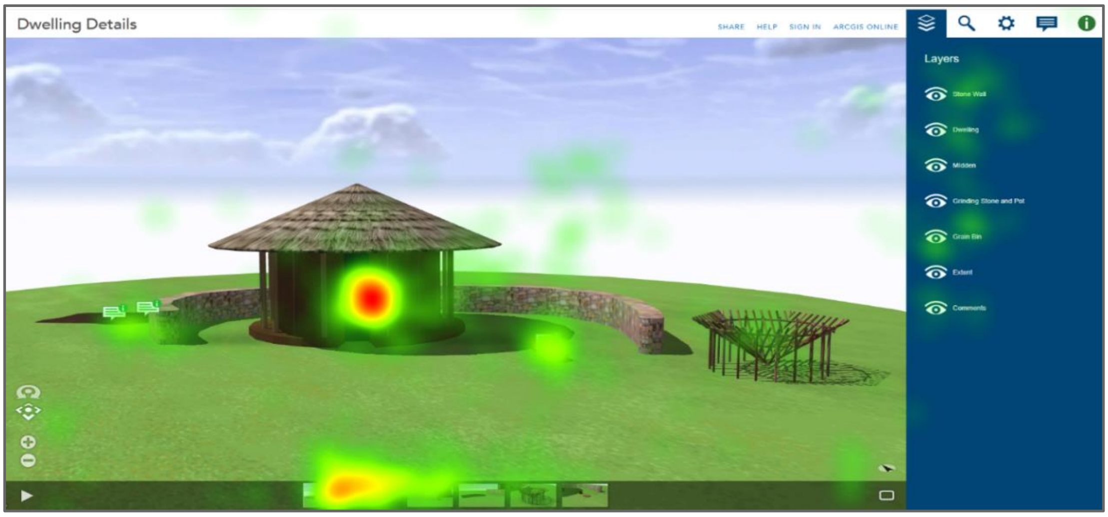

Figure 52. Gaze-fixation Heatmap for the Interactive Dwelling Visualization

The fixations on the comment-callout icons are evident in the more intense fixations on the dwelling, stone wall, midden and grinding stone models that had visible comment-callout icons compared to the less intense fixation on the grain bin, which did not have a visible comment-callout icon in this view. The comment-callout icons are effective in attracting the attention of participants, and thus, made the layout of educational material effective. Participants were clearly made aware of the areas of interest (the 3D objects) of educational value. In this regard, 3D visualizations with comment-callout icons are an effective way to communicate descriptions of objects in the 3D visualization.

For further evaluation, participants were asked to describe the attractive qualities of the 3D visualization in the post-study survey. Besides the result of the heatmap, participants rated graphics and realism as the most attractive quality. Ease of navigation and the uniqueness of the visualization rated similarly (Figure 53). Furthermore, when asked about the organicness and realism of the models, participants, it was rated as moderate or a lot (Figure 54).

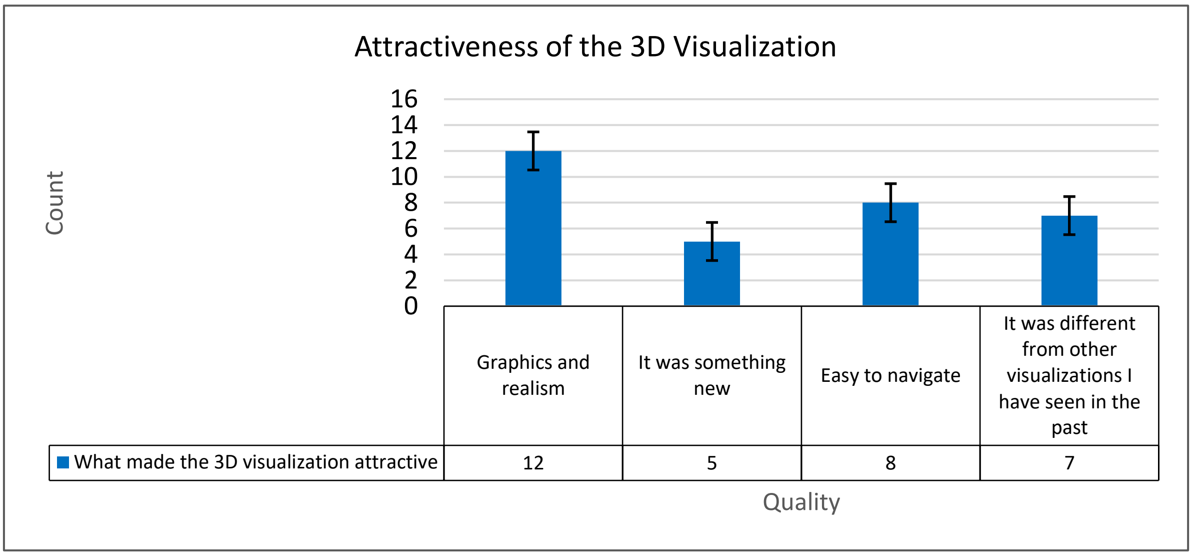

Figure 53. The attractiveness of the 3D Visualization as Rated by Participants (choose one or more)

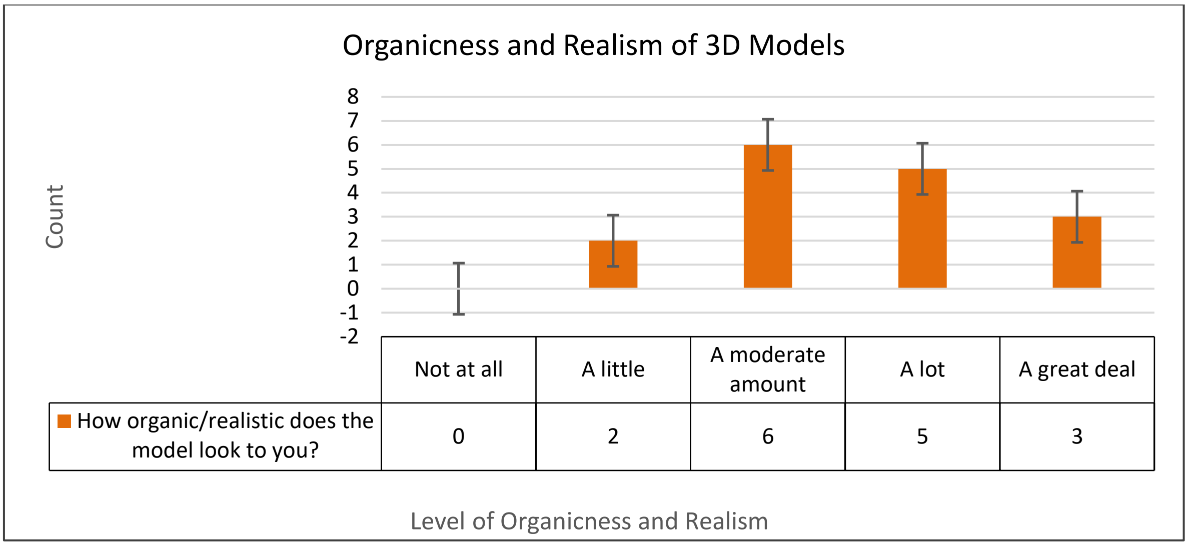

Figure 54. Participants' Rating of the Organicness and Realism of the 3D Models

6.4.3 Completion of a Task in the Archive

There are several links to the *Metsemegologolo* archive within the story map. A general user of the story map would likely have no prior experience using an archaeological archive. To observe how participants interact with the archive and search for information, participants were prompted to open the archive and attempt to download Shapefiles (spatial data of the stone walls - Table 6) from it. The task can be completed with two clicks from when the archive page is fully loaded. Considering this, the participants took an average time of 42 seconds to complete the task, with the minimum time being 13 seconds and the maximum time being 84 seconds (Figure 55). Many participants showed confusion as to how the task should be completed and required assistance and verbal prompting to complete the task. Several participants expressed their opinion that they expected to see a large visible *'Download'* button somewhere on the page.

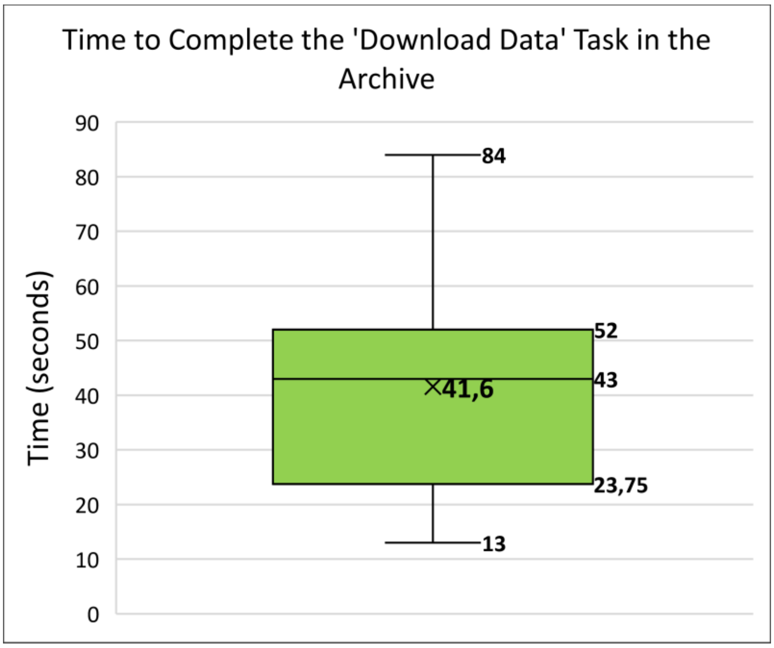

Figure 55. Box and Whisker Plot of Participant's Task Completion Time in Seconds

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How participants started their search for information was also assessed. The assessment was conducted by reviewing the recordings of the participants completing the task. The software was unable to generate heatmaps or gaze fixation maps due to the amount of movement from participants scrolling through the archive, so the recordings were reviewed manually. The recordings showed the succession of participants eye movements as a moving red dot that visualizes gaze fixations. The dot increases in size in response to the duration of a participant's fixation. Reviewing the footage showed that when starting the task, 31% of participants started their visual search for the 'download' link at the top of the archive page. 13% of participants started at the bottom of the page, gravitating towards a link to export objects as PDFs or as XML. Interestingly, 56% of participants correctly started their visual search at the middle of the page, where the 'download' link for Shapefile objects is located. However, most participants could not identify how to navigate to the Shapefiles and continued to search other parts of the page. Even when participants noticed the Shapefiles, they were unsure of how to proceed in order to complete the task of downloading the spatial data.

6.4.4 Visual and Auditory Focus Level

The video at the end of the story map is that of the 3D scene of the Northern cluster of Seoke (Section 4.2.4) that visually and auditorily summarises all of the information from the body of the narrative. Participants were prompted to watch the video while their eye movements were tracked. The footage of the participants' eye movements was evaluated to determine their attention level for each section of the video. Similar to the approach for the evaluation of the archive above (Section 6.4.4), the footage of participants' eye movements showed the succession of participants' gaze fixations visualized as a red dot. As the video is split into very clear sections, participant attention levels were determined by the level of agreement between eye movements and the subject of the video voice-over (i.e., determining if a participant fixated on the dwelling model when the voice-over discusses dwellings). Attention levels were classified into 3 groups (Figure 56), namely:

i) Focused: Participant fixated mostly on the subject of the voice-over.
ii) Scattered: Participant fixated on the subject of the voice-over, but also fixated on other objects.
iii) Unfocused: Participant fixated on an object unrelated to the voice-over for a prolonged period.

Video sections that showed a more zoomed-out view of the object it discussed had more participants that had scattered attention. The zoomed-out view had several unrelated objects in frame with the object discussed in the voice over. The participants' scattered attention could be due to the participants' curiosity about the 3D scene in general. The zoomed-out sections include the *Introduction, Dwelling Cluster, Grinding Stone* and *Middens* sections. An exception is the Stone Walls section. Participants tended to look at the stone wall models in this section even though there was a lot of movement in this section of the video. Video sections that showed a more zoomed-in view of the object it discussed had more participants that had focused attention. The zoomed-in sections include the *Dwelling Description, Cattle, Crops* and *Grain Bin* sections. Video sections where participants were unfocused include the *Dwelling Cluster, Grinding Stone, Cattle, Middens* and *Grain Bins* sections. These sections, except the *Dwelling Cluster* section, were the sections with the longest voice-overs. Out of the 16 participants, six experienced unfocused attention. These participants

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experienced unfocused attention for only one section out of the video, except for one participant that experienced unfocused attention for two sections out of the video.

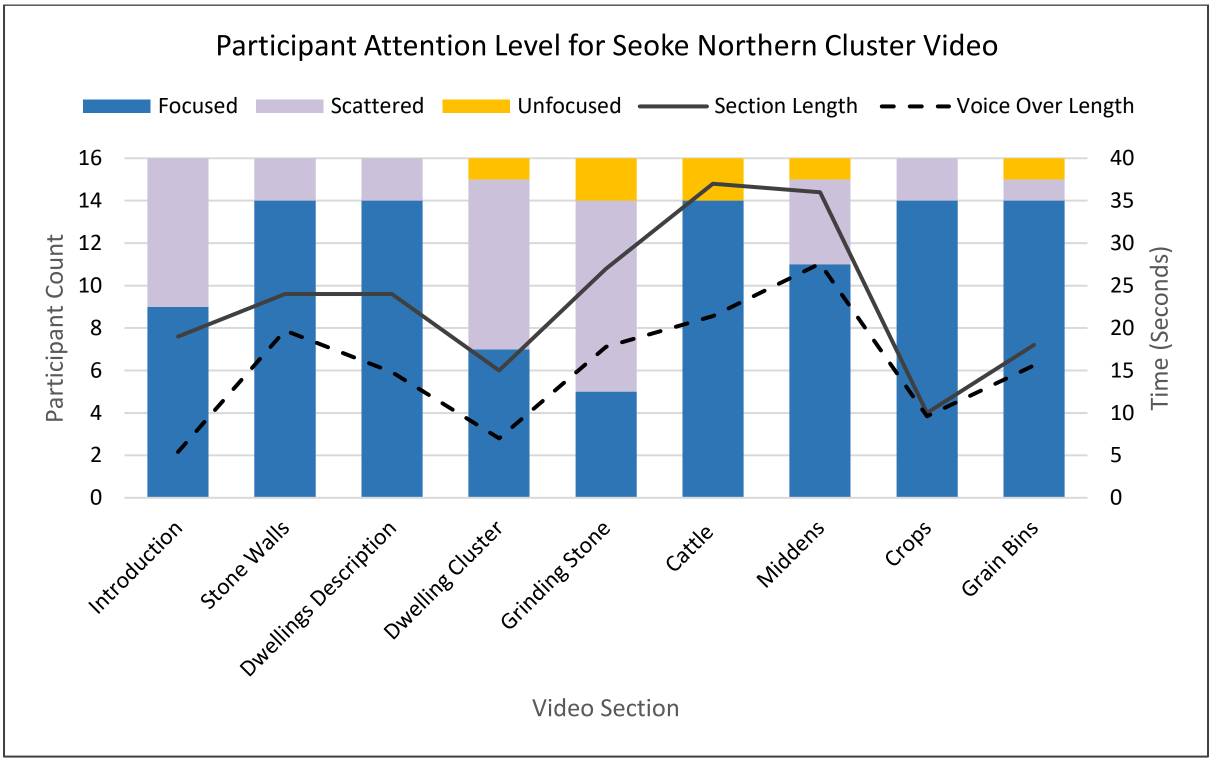

Figure 56. Attention Levels of Participants While Viewing the Seoke Northern Cluster Video

In the post-study survey and conversations, some comments were made about the video. A few participants communicated that they preferred watching the video to reading the content of the story map as the video summarized some information found in the text. These participants did clarify that they are auditory learners rather than visual learners.

6.4.5 Interactivity

Besides the static forms of information in the story map such as the textual information, images, and 2D maps, the story map also has many dynamic and interactive auxiliary content. The level of interactivity from participants in seeking information in the story map was evaluated. Five actions were identified to determine the extent to which participants interacted with the story map. The story map is structured linearly and can be navigated by simply scrolling down to the next section. Actions that break apart from the linear flow of the story map were categorized as an 'interaction'. These interactions include - opening a link to the archive, opening a link to a 3D visualization, opening the legend bar of the web map, opening an attribution and maximizing an image.

Opening the links to the archive and a 3D visualization were the most pronounced actions presented to the reader. Participants were instructed through the text of the story map to open the links, and the buttons to do so were quite prominent (Figure 57). To make the buttons prominent, filled buttons of a contrasting colour, noticeable size and labelled with their function, were used. Overall, 44% of

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the participants opened the link to the archive, and 50% of participants opened the link to a 3D visualization (Figure 58).

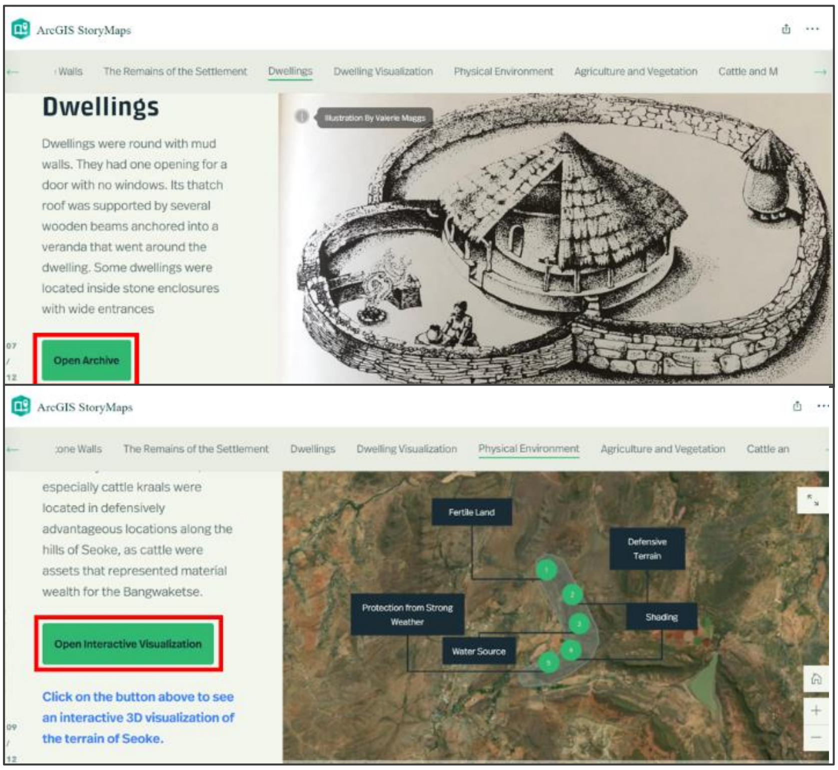

Figure 57. Interactive Buttons Linked to the Archive and Interactive Visualizations

The archive acts as a starting point for readers that are searching for information beyond what is presented in the story map. Although valuable, the archive is auxiliary information that is not integral to the flow of the story map's narrative and as such, readers do not have to interact with it. Considering that the participant group mostly rated their interest level in the subject as 'casual' and 'short-term', the group's relative level of interactivity with the archive is promising.

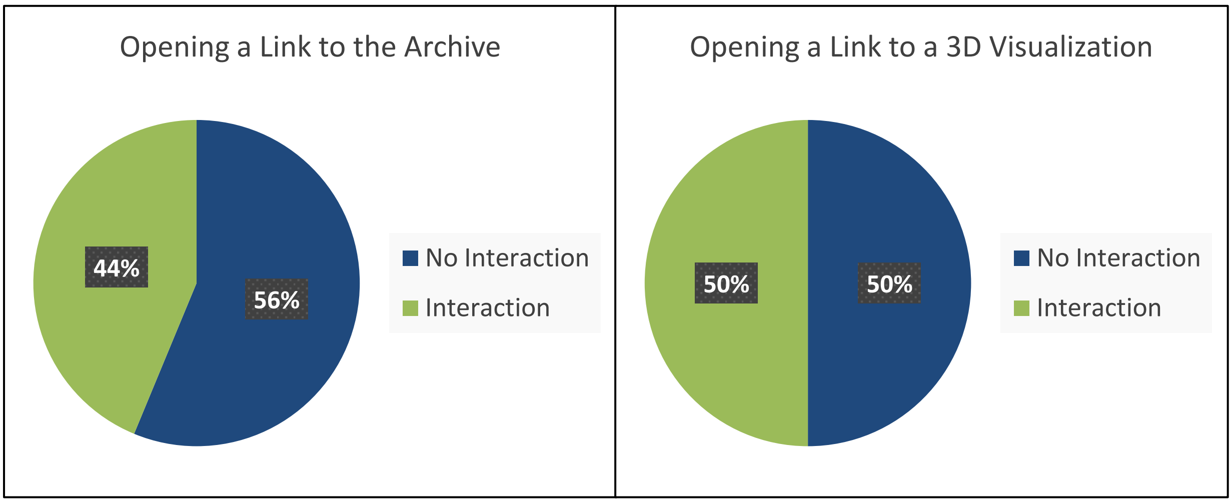

Figure 58. Percentage of Participants that Opened Links to the Archive and the 3D Visualization

A previous iteration of the story map had the 3D visualizations embedded into the main page. Due to load time issues, it was decided that adding a button that opened the visualization in a new tab would be a better alternative. However, as only half of the participants opened the visualization, opening the

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visualization using a button has its share of weaknesses. Readers do have an alternate opportunity to see the visualization of the site through the video at the end of the story map, although the video is not interactive. The level of participant interactivity with the 3D visualization button needs to be improved through further work, as the 3D visualization is an important component in learning about a site remotely. The actions that were less pronounced to the reader include maximizing an image, opening the legend bar of the web map and opening an attribution. These actions required the participants to notice less prominent details of the story map to identify the buttons related to the actions.

Amongst the textual information of the story map, several images work to provide references related to the text (Figure 59). With regards to maximizing an image, 19% of participants performed this action (Figure 60). As maximising images did not perform well in terms of interactions from participants, it would be better to use simpler images within the text and to use more complex images in the main stage of the story map. Readers are less likely to maximise and examine the smaller images amongst the text, so images with important details may not be presented to their best potential through this method.

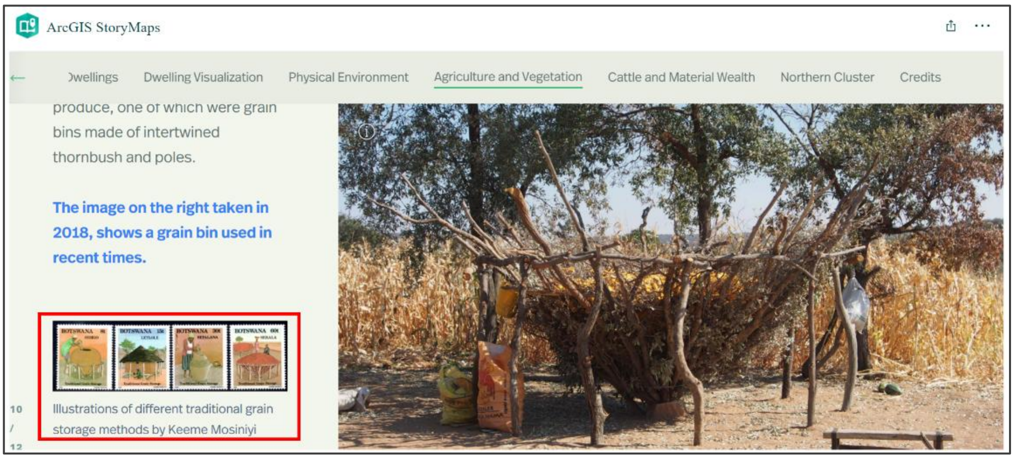

Figure 59. Maximizable Image

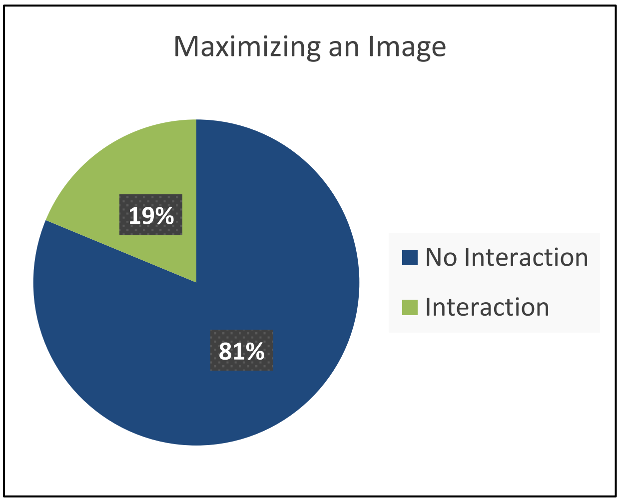

Figure 60. Percentage of Participants that Maximized Images

Participant interactions with the legend bar and attribution were tested differently. Both actions are presented using floating action buttons. After noticing a lack of interaction with the above-mentioned components during the eye-tracking study, some participants were prompted to complete these

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actions (Figure 61). Participants were prompted with questions such as *"where is the legend for this web map?"* and *"Please tell me the name of the photographer for this image"*. For opening an attribution, 13% of participants completed the action without a prompt. With opening the legend bar for the web map, no participants completed the action without a prompt. Of the participants that were prompted to open an attribution or the legend bar, all were able to complete the action (Figure 62).

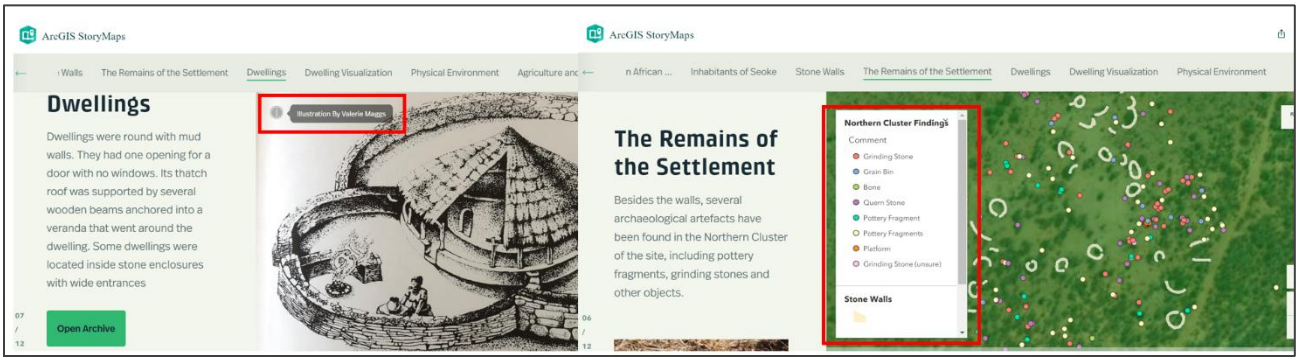

Figure 61. Attributions and Legends

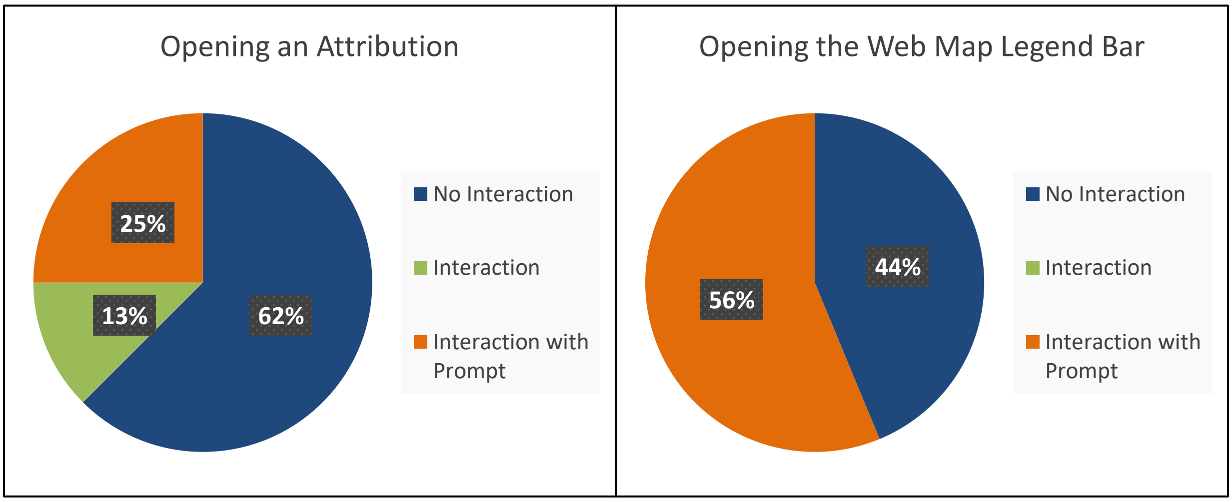

Figure 62. Percentage of Participants that Opened Attributions and Opened the Legend Bar

The attributions, similar to the archive links discussed previously, acts as a starting point for readers that are searching for information beyond what is presented in the story map. The attributions are valuable in that they provide credit to the authors of various photographs and illustrations and act as a reference for a reader if they choose to learn more about Seoke and the Bangwaketse in their own time. However, the attributions are auxiliary and not integral to the flow of the story map's narrative. In contrast, the web map legend plays an important role in the richness of the content in the story map. The web map's legend is integral for understanding the web map as it provides a reference for the various remains found at the site that are represented by points on the map. The lack of interaction with this function in the story map means that it may be necessary to provide readers with the information provided by the legend through other means or to specifically instruct readers to open the legend through the textual information.

6.5 Discussion

The eye-tracking study revealed important insights regarding the reader's focus and attention while interacting with the story map. Adding onto the evaluation and discussion of system-level usability done in Chapter 5, the eye-tracking study places focus on how the platform is used. Assuming a relation between visual and mental attention patterns (Wang et al., 2019), the story map was evaluated on how it attracted user focus, how users completed tasks and how they interacted with the story map overall. The story map performed well generally, with some identified areas for improvement.

It was found that educational material, namely the 2D map and 3D visualization, was laid out effectively, therefore supporting the learning process. Learning can be affected when learners are presented with ineffectively laid out educational material. Negative feelings of frustration, confusion and anxiety can overshadow any learning that was done (Jardodzka et al., 2017; Van Nuland et al., 2017). Comparatively, effectively laid out educational material provides learners with all the means necessary to support the task of learning (Brooke, 2013). The cumulative gaze-fixation heat maps clearly showed that participants' attention distributed across areas of interest of educational value, namely, the text, map, insert map, legend and corresponding symbols in the '*Pre-colonial Southern African Settlements*' section and the comment-callout icons in the 3D visualization. As the cumulative gaze-fixation heat maps showed no intense fixations on content irrelevant to the reader's learning, it can be concluded that the 2D map and 3D visualization presented educational content clearly and that participants could identify the educational content presented. Participants did not expend their energy searching for the educational value in the content instead of learning, meaning that these sections were also efficiently laid out (Brooke, 2013).

Furthermore, the video of the Northern cluster 3D scene performed well overall for participant attention levels. Reviewing footage of participants' gaze fixations while watching the video, attention levels were categorised as focused, scattered or unfocused, based on the agreement between visual attention patterns and the auditory and visual stimulus of the video. While watching the video, it was found that participants were mostly fully focused on the subjects discussed in the voice-over (which corresponded to the video visual). Participants also experienced scattered attention, especially for more zoomed-out sections of the video. The scattered attention was assumed to be caused by participants' curiosity about the other objects visible in the zoomed-out view, as the participants did fixate on the subject of the voice over as well. However, in instances where a video section was longer or very zoomed out, a small proportion of participants did experience unfocused attention. Adding to the evidence of attention paid to the video content, participants reported that the graphics and realism of the 3D models was the most attractive quality of the visualization. Interestingly, participants who are self-proclaimed auditory learners especially noted that the video and voice-over were helpful for them, which highlighted an unintended dimension of value and purpose of the video.

Cognitive overload was an issue of concern that influenced how the 3D content in the story map - the simple interactive 3D visualizations and the video of the Northern cluster – was presented (Sections 2.3.2 & 4.2.4). Cognitive overload has been found to be caused by the manipulation of dynamic 3D models, immersive 3D games and hypermedia for 3D learning (Berney et al., 2015; Gerjets & Scheiter, 2003; Paas et al., 2003; Huk, 2016), as these individuals must process a difficult task that exceeds their

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mental ability (Hossain & Yeasin, 2015). Negative feelings felt while learning – such as those from cognitive overload may lead to avoidance attitudes, which limits how much of what was learned being processed (Kremer et al., 2019). However, as shown by participants' visual attention patterns, what little avoidance that participants showed was minor.

An area that highlighted a point of improvement is the sections of the story map that displayed images as the main media was found to have had an unbalanced distribution of attention. The cumulative gaze-fixation heatmaps show that participants' attention was highly focused on the textual information. Any fixations on the images were brief, scattered and not intense. Considering the unbalanced distribution of attention and in assessing participant's first gaze fixations, interestingly, approximately 50% of the participants looked at the images first. Thus, it can be said that the lack of attention paid to the images was not due to unattractiveness. The images were able to attract the attention of users but could not hold their attention.

The 2D map, 3D visualization and images are similar, in that they are all visually oriented. However, the images performed quite differently than the 2D map and 3D visualization regarding gaze fixations. One major difference that may have contributed to the difference in performance is that the 2D map and 3D visualization had clear visual cues or focal points of their educational value whereas the images did not. The 2D map had a legend and labels and the 3D visualization had comment-callout icons that drew the participants' attention and clearly communicated that educational content was available. These visual cues may have grabbed and held the attention of participants better, by being visual indicators that there is valuable information in not just the text, but the media. The lack of similar visual cues or focal points in the images used in the story map may have been a factor for the lack of attention paid to the images and the scattered nature of fixations overall. As the participants were not knowledgeable about pre-colonial southern African settlements, they may not have had the prior knowledge needed to evaluate an archaeologically significant image and to extract the relevant information from it. Overall, it was concluded that story map sections presenting images with educational value must be displayed with more context and the focal point of the image must be highlighted. It may be beneficial to clearly outline what readers are meant to gain or observe from the images. Labels or icons could work as visual cues to guide the attention of the reader to the relevant educational material within an image. This, in turn, will support users in not wasting energy by expending it while searching for educational content in the images and thus, make the layout of these sections more efficient for supporting learning. Also, clearly guiding users to the educational value of archaeological images will make the presentation of educational content in this manner more effective. Participants will get the most out of learning through the images, instead of relying solely on their own interpretations.

How participants searched for information in the archive also revealed that there are improvements to be made. Many participants showed visible confusion and required assistance to complete the task of downloading spatial data from the archive. Participants took an average time of 42 seconds to complete the task, which can be completed with two mouse clicks. Considering the time it took for participants to complete the task and the participants' confusion, this may be a factor that affected the efficiency of the story map. In Section 5.7, it was elaborated that the story map was more effective and satisfying to use, moreso than the story map being efficient to use. As the participants exerted effort and resources (time) while trying to complete the task of downloading data, the usability of the story map can be improved by making this task more efficient. Participants were not confident when

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attempting to complete the task. Utilizing commonly used GUI functionalities such as a UX call to action button may make the archive more familiar and accessible to a wider variety of users.

Lastly, the components of the story map that may have affected its efficiency were the various buttons for opening auxiliary contents that remove the reader from its linear narrative. The extent to which participants interacted with the story map outside of the linear flow of the main narrative was evaluated. There were several UX buttons or icons (i.e., floating action and filled buttons) that participants could click on to reveal auxiliary data and information. Due to the moderate to poor level of interaction with the story map in this manner, educational material that is integral to the learning process should be kept within the main linear flow. The more visually prominent, call to action, filled buttons for opening the archive and the interactive 3D visualizations were of a contrasting colour, large size and labelled with their function to attract engagement (Fanguy, 2018). Despite this, engagement with the story map in this manner was not high – at 50% for opening the visualization and at 44% for opening the archive. The less visually prominent floating action buttons for opening the attributions performed worse – at 13% unprompted engagement for opening the attribution and no unprompted engagement for opening the legend bar. Prompting participants to engage with the floating action buttons did show that the buttons were intuitively placed, however, with 25% engagement for opening attributions and 56% engagement for opening the legend bar.

The actions of opening the 3D visualization and opening the legend of the web map were integral to the readers' learning process. The UX buttons in the story map were utilised for the function of improving the effectiveness of the story map – that is, to provide users with all of the necessary resources needed to support the task of learning (Brooke, 2013). Providing access to the archive, interactive 3D visualization, attributions and legend using the buttons functioned as access to auxiliary educational content that supported what was being taught through the main textual narrative and media in the story map. Although valuable for the learning process, these contents may likely be looked over by a significant proportion of users. With these findings, it is recommended that although the auxiliary content is valuable if the content is integral to the core learning process or crucial to the main narrative of the story map, it is better to keep the content within the main linear flow of the story map.

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Chapter 7: Conclusion

7.1 Research Summary

Seoke and many other similar sites in the southern African region are physically and conceptually inaccessible to the public due to private land ownership, their tough terrain and the current Covid-19 pandemic. A story map was developed as an exploratory digital environment for learning about Seoke in response to the educational potential of Seoke in light of its physical and conceptual inaccessibility. This research aimed to develop an exploratory digital environment for Seoke and to assess its usability for facilitating learning about pre-colonial southern African history and urbanism in space and time.

To achieve this aim, the following key findings of the study correspond to the outlined objectives:

i. **Develop an exploratory digital environment for learning about Seoke:**

The story map was created as an exploratory digital environment for learning about pre-colonial southern African urbanism in space and time. To create the story map, a narrative with a clear structure encompassing an introduction, body and conclusion was written. For a story map rooted in cultural heritage, it is important that the narrative and the accompanying visual elements place the Bangwaketse as the main character and that original place names and nouns are used where possible. Adding to this, the story map successfully integrated various textual, archival and spatial information utilizing various forms of media.

Of the spatial information integrated into the story map, 3D visualizations of the site were built using Esri CityEngine. The 3D scene spatially organised existing objects in the archaeological record with geospatial attributes and illustrated the site analogous to how it would have appeared at the time that it was inhabited. By visualizing geospatial information for Seoke in 3D, the 3-dimensional characteristics of the objects in the archaeological record were more expressively represented as the nuances and details of the site were visualized, facilitating the conceptualisation of the physicality of the site. To capture functional realism, the 3D models provided a visual reference for objects that are niche or not mainstream, through the visual cues of their materials, dimensions and construction. However, using Esri CityEngine to model a scene that is not a modern cityscape resulted in models that are too clean and geometric, which in turn made the 3D scene appear more inorganic than the real site.

ii. **Test the usability of the story map for facilitating learning by developing and conducting a usability survey and an eye-tracking study:**

To test the usability of the story map as an environment for learning, the story map was evaluated through a usability survey and an eye-tracking study. The usability survey was conducted online and was distributed to university students enrolled in two South African universities and one Botswana university. The eye-tracking survey was conducted in person at the University of Pretoria's eye-tracking lab.

The usability survey evaluated the story map as a system for facilitating learning by gathering user feedback in addition to testing the story map's effectiveness, efficiency, user satisfaction and learning. To do so, the survey consisted of five sections of questions, namely demographics, usability 3D

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visualization, value and perception. The demographics section gathered the participants' non-personal information, prior academic and system experiences. The usability section gathered feedback on the story map's system-level usability using a System Usability Scale (SUS) questionnaire. An evaluation of participants' level of information retention and confidence in their answers was conducted in the 3D visualization section. To gather the participants' feedback on the story map, the value section collected feedback on the pedagogical value of the story map and the 3D visualization. Lastly, the perception section evaluated how participants perception of the 3D visualizations, pre-colonial southern Africa and what was learned through the story map.

The focus of the eye-tracking study was to evaluate how participants interacted with the story map while learning. The participants' eye movements were tracked while they read through the story map and completed prompted tasks. The eye-tracking story gathered information on the distribution of participants' attention across textual information and media, how participants completed a task in the archive, participants' visual and auditory focus level for the 3D visualization video and participants' interactions with auxiliary content.

iii. **Analyze the results to draw conclusions and provide recommendations on the usability of story maps to facilitate learning about pre-colonial southern African history and urbanism in space and time and to inform the further development of the platform:**

The story map was an effective learning tool. Overall, the story map was effective in accomplishing the aim of the study, which was to create a platform for learning. Participants were able to learn while using the story map and performed well when recalling information and applying information learned.

iii.(a) Usability Survey

For the SUS questionnaire (Brooke, 1996) conducted for the story map, an average score of 65 was calculated, which can be interpreted as a good system usability score (Bangor et al., 2008). At the system level, evaluation through the usability questionnaire and the eye-tracking study found that the story map was effective as the content needed to support learning was all well integrated, and that it was satisfying to use, as participants wanted to use the platform again. The efficiency of the story map (namely the time and energy resources needed to use the story map) was average (Brooke, 2013). Participants did feel that the story map required technical support and some prior knowledge to navigate. The eye-tracking study showed that participants especially struggled with navigating the archaeological archive.

For a more detailed evaluation, the average SUS score for 24 groups within the participant population was calculated. Within the groups, it was found that 63% performed better or the same as a score of 65, the average SUS score for the population. Participants with practical experience with story maps, those enrolled in a related course and postgraduate students scored the usability of the story map the highest. Comparatively, participants who were not comfortable with English, not comfortable with using a computer and those with no practical experience with Google Maps scored the story map's usability the lowest. The groups that scored the story map's usability the lowest scored questions about the technical support and prior knowledge needed to use the story map especially poorly. The group demographics cannot be used as a metric to definitively measure for whom the story map is best catered. However, it can be inferred that participants who are uncomfortable with English, with using computers and have no practical experience with Google Earth, strongly think that they would need the support of a technical person and would need to learn a lot of things to use the story map.

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It can also be inferred that the actual technical support and prior knowledge needed to use the story map may be related to the language or jargon used in the story map or the technical computer skills needed to use and understand story map, considering that practical experience with Google Earth was used as a benchmark for experience with web maps.

On a short test for participants' information retention regarding what was taught through the story map, participants had an average answer accuracy of 73%. Participants' average self-rated confidence for their answers was 69%. A strong positive correlation of 0.7 showed that the participants' self-rated confidence increased as the average answer accuracy for the test questions increased. Self-rated confidence itself was not strongly correlated to whether participants answered the test questions 100% correctly or not. Confidence while learning is indicative of a learner's expectation of positive results after exerting effort to learn, reflecting positive emotional, cognitive and performance effects (Moller, 1993; Norman & Hyland, 2003). Participants' self-rated confidence not being strongly correlated to their accuracy, shows that participants were motivated to learn and expected positive results from what they learned.

iii(b) Eye Tracking Study

Analysis through the eye-tracking study found that media with clear visual cues that draw attention to educational material and were part of the main linear flow of the story map's narrative received better reader attention and focus. Of the media, the 2D maps, interactive 3D visualizations and video performed the best for reader attention on areas of interest for educational value, whereas the images and interaction with auxiliary content did not perform well. The use of visual cues for indicating areas of interest for educational information in the media of the story map was an effective method in assuring a balanced distribution of attention in the textual information and the media. As a lot of the media is niche - namely 2D maps, archaeological images and photographs, 3D models of archaeological objects - guiding readers to learn using cues indicating educational value will ensure that users can get the most out of the learning process without expending energy trying to extract or understand information that they are unfamiliar with form the text or media.

iii.(c) Pedagogical Value and Perception

As a platform for learning the story map received positive feedback with, 76% of participants believing that the story map is an innovative way to learn about Seoke. The participants rated the pedagogical value of the story map positively, with 79% believing that the concept of a 'virtual field trip' is valuable. As a digital exploratory environment, the story map provided a platform to learn about Seoke's history, but also provided a digital alternative to learning about the physicality of Seoke through the 3D visualizations, as it is for traditional field trips.

As addressed in the key findings for objective 1, the 3D models were built to capture functional realism, not hyperrealism. Nevertheless, this did not affect the readers' perceptions of the organicness and realism of the 3D scenes and readers were enthusiastic and reacted positively regarding the models. Participants perceived the models to be realistic and their graphics and realism to be their most attractive attribute, with 77% reporting that the models helped them to imagine what it would be like in a pre-colonial southern African settlement. Furthermore, participants perceived the 3D visualizations to be of high pedagogical value. 70% of participants agreed or strongly agreed that the 3D models helped with understanding the physicality of the site and 72% reported that the 3D models made learning about Seoke more engaging. With the self-reported value and reliance on the 3D

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visualization, however, developing the 3D models further, based on the key findings of objective 1, would be valuable.

7.2 Future Work

As part of the *Metsemegologolo* project (Section 1.1; Annex 1), this research was a case study for a project that plans to expand. The project aims to create an open-source, online platform that presents archival and spatial information related to early Tswana urbanism. Seoke was selected as the site of interest for this case study, however, there are four other similar archaeological sites in the southern African region that in future work, will be included in the digital exploratory environment. Future work will involve taking the findings of this study to inform the future iterations of the story map to improve and expand the scope of the exploratory environment to include the other identified archaeological sites.

In this regard, the key considerations for future work are as follows:

i. Development of the 3D Models and Scene

The 3D models were built with functional realism to convey the shape, scale, materials and locations of the objects depicted. However, software that can depict organic shapes, texture and terrain may be better suited for modelling the spatial characteristics of sites similar to Seoke. CityEngine was a useful software to use as it comes with great support, namely documentation and hosting services, which make sharing models and scenes online easy. However, as CityEngine is catered to modelling cityscapes, the models and scenes were not able to capture the visual nuances of the site accurately. Although participants were not affected by the level of realism presented by the current 3D scenes of the site, the reported reliance on the models in the understanding and conceptualising Seoke, calls for further development of the models.

ii. Interaction with Auxiliary Content

Participants are more likely to remain on the story map's main narrative. Auxiliary content that requires clicks to open or opens in new tabs may be missed by participants. If the content is vital to the educational value of the story map, it is better to embed that content into the main stage of the story map.

iii. Distribution of Attention for Images

Images performed poorly regarding the visual attention and focus of participants. Participants were more likely to glance briefly at images or look at the images in their peripheral view. This was likely because the educational value of the images was not made clear to the reader. As participants were not knowledgeable about precolonial southern African history or settlements, they may not have had the prior knowledge needed to evaluate an archaeological image and to extract the relevant information from it. Visually indicating the knowledge that can be gained from an image may work in attracting the reader's attention. Labels or icons could work as visual cues to guide the attention of the reader to the relevant educational material within an image.

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iv. Navigation of the Archive

As mostly having no prior experience with digital archaeological archives, participants struggled with navigating the archive and extracting data from it. Providing a user interface and UX functionalities that are simpler and more familiar and intuitive for first-time archive users may be better suited for the intended users.

7.3 Contributions

This study developed, implemented and tested an exploratory digital environment for learning about pre-colonial southern African urban settlements. In response to the traditional and continual misconceptions and misrepresentation of pre-colonial Africa, a platform to provide viewing and learning opportunities was developed for Seoke, an archaeological site in present-day Botswana. This was a first for pre-colonial urban settlements in the southern African region. The learning environment, presented as a story map, displayed geospatial, historical and archival information about Seoke through various forms of media, including a 3D visualization of the settlement. The evaluation of the learning environment using participant feedback highlighted the strengths of the environment in facilitating learning and indicated points for further improvements, with the intention of expanding the digital learning environment to encompass additions of similar archaeological sites.

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Annex

Annex 1: List of Metsemegologolo Collaborators

Name	Affiliation	Role
Stefania Merlo	Mapping Africa's Endangered Archaeological Sites and Monuments, Department of Archaeology, University of Cambridge	Coordinator
Justine Wintjes	Department of Human Sciences, KwaZulu-Natal Museum	Coordinator
Anton Coetzee	Wits School of Arts, Wits University	Coordinator
Serena Coetzee	Department Geography, Geoinformatics and Meteorology, University of Pretoria	Member
Azizo da Fonseca	Wits Digitisation Centre, Wits University	Member
Amanda Esterhuysen	School of Geography, Archaeology and Environmental Studies, Wits University	Member
Jennifer Fitchett	School of Geography, Archaeology and Environmental Studies, Wits University	Member
Simon Hall	Department of Archaeology, University of Cape Town	Member
Clare Kelso	Department of Geography, Environmental Management and Energy Studies, University of Johannesburg	Member
Vuyiswa Lupuwana	Department of Archaeology, University of Cape Town	Member
Brenda Maina	Department Geography, Geoinformatics and Meteorology, University of Pretoria	Member
Fred Morton	History Department, University of Botswana	Member
Malebogo Mvimi	Muséum National d'Histoire Naturelle	Member
Thapelo Otlogetswe	English Department, University of Botswana	Member
Victoria Rautenbach	Department Geography, Geoinformatics and Meteorology, University of Pretoria	Member
Giuseppe Salemi	Archaeology Department 3D technology, University of Padova	Member
Phillip Segadika	Archaeology Unit, Botswana National Museum	Member
Keletso Sethlabi	History Department Archaeology, University of Botswana	Member
Lokwalo Thabeng	History Department Archaeology, University of Botswana	Member

Annex 2: CGA code for stone wall models

```
#------------------Attributes------------------#
rock                          = "facade_textures/walltex4.jpg"
#-----------------Wall Segments----------------#
segment(area)          = case geometry.area <= 5 : rand(0.1, 0.3)
                                 else : rand(0.7, 1)
#----------------Starting Rules----------------#
Lot -->
        extrude( segment(geometry.area) ) Wall
#------------------Enclosures------------------#
Wall -->
        comp(f) { top : Top | side : Sides}
#--------------------Sides--------------------#
Sides -->
        offset(-0.8)
        setupProjection(0,scope.xy, rand(1.5, 2), 1.4, rand(1.5, 2), 1.4)
        set(material.bumpmap,rock)
        projectUV(0)
        texture(rock)
#--------------------Top---------------------#
Top -->
        offset(-0.5)
        setupProjection(0,scope.xy, rand(1.5, 2), 1.2, rand(1.5, 2), 1.2)
        set(material.bumpmap,rock)
        projectUV(0)
        texture(rock)
```

Annex 3: CGA code for dwelling models

```
#-------------------Textures--------------------#
roof_texture                  = "facade_textures/Roof_v4.jpg"
wall_texture                  = "facade_textures/Mud_Wall_1.jpg"

const halfarc_asset           = "facades_objects/arc_thin.obj"
const wall_inset              = 0.3
attr door_index               = 4
#----------------Starting Rules-----------------#
Lot --> extrude(3) Building
                softenNormals(180)
#-------------------Dwelling-------------------#
Building -->
        comp(f) { top : Top
                        | door_index : DoorTile
                        //|(door_index(geometry.area) - 2) : WindowTile
                        //|(door_index(geometry.area) + 2) : WindowTile
                        | left : Wall
                        | right : Wall
                        | back : Wall
                        | front : Wall }
```

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```
SolidWall -->
        i("builtin:cube:notex")
        s('1,'1,wall_inset) t(0,0,-wall_inset)
        Wall
#---------------------Door---------------------#
DoorTile -->
        split(x){ ~0.1 : SolidWall
                | ~1.5 : split(y){ ~1 : Door | scope.sx/2 : Arcs }
                | ~0.1 : SolidWall }

Arcs -->
        s('1, '1, wall_inset) t(0, 0, -wall_inset)
        Doortop
        i("builtin:cube")
        split(x){ ~1 : ArcAsset
                        | ~1 : r(scopeCenter, 0, 0, -90) ArcAsset}

Doortop --> color("#20222D")

Door -->
        color("#20222D")
        t(0, 0, -wall_inset)

ArcAsset --> i(halfarc_asset) Wall
#--------------------Walls---------------------#
Wall -->
        setNormals(soft)
        texture(wall_texture)
        setupProjection(0, scope.xy, rand(2,3), rand(2,3), rand(2,3), rand(2,3))
        projectUV(0)
        set(material.bumpmap,wall_texture)
#---------------Roof + Overhang----------------#
Top -->
        roofHip(25, 1.6) Roof
#-------------------Thatch---------------------#
Roof -->
        set(trim.vertical, true)
        comp(f){all : Thatch}

Thatch -->
        setupProjection(0, scope.xy, 2.1, 2.1, 2.2, 2.2)
        set(material.bumpmap, roof_texture)
        texture(roof_texture)
        projectUV(0)
        extrude(vertex.normal, 0.05)
```

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Annex 4: CGA code for dwelling veranda and beams

```
#-------------------Attributes--------------------#

attr height                    = 2.5
attr door_index          = 4

beam_texture                   = fileRandom("*facade_textures/Plank_v*.png")
veranda_texture                         = "facade_textures/Mud_Wall_1.jpg"
const beam_asset1              = "facades_objects/stick01.FBX"
const beam_asset2              = "facades_objects/stick02.fbx"
const beam_asset3              = "facades_objects/stick03.FBX"
#-----------------Starting Rules-------------------#
LotInner -->
   Lot

Lot -->
   offset(0.6) A
#---------------------Border----------------------#
A -->
          comp(f) { door_index - 2 : NIL
                       | border : extrude(world.up, height) O }
#----------------Veranda + Beams------------------#
O -->
          split(y){ 0.2 : Veranda
                             | 0.8 : GenericBeam}
#---------------------Beams-----------------------#
 Beam1 -->
            i(beam_asset1)
            r(scopeCenter, rand(0, 180) , 90, 0)
            t(-0.1, 0.3, 0.2)
            s('3.2,'0.2,'(rand(0.1, 0.4)))
            setupProjection(0,scope.xz,4,4,1,1)
            texture(beam_texture)
            projectUV(1)

  Beam2 -->
            i(beam_asset2)
            r(scopeCenter, rand(0, 180) , 90, 0)
            t(-0.1, 0.3, 0.2)
            s('3.2,'0.2,'(rand(0.1, 0.4)))
            setupProjection(0,scope.xz,4,4,1,1)
            texture(beam_texture)
            projectUV(1)

 Beam3 -->
            i(beam_asset3)
            r(scopeCenter, rand(0, 180) , 90, 0)
            t(-0.1, 0.3, 0.2)
            s('3.2, '0.2,'(rand(0.1, 0.4)))
            setupProjection(0,scope.xz,4,4,1,1)
            texture(beam_texture)
```

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```
            projectUV(1)

 Beam -->
            40% : Beam1
            40% : Beam2
            else : Beam3

 GenericBeam -->
            primitiveCylinder(16, rand(0.05,0.07), height)
            setupProjection(0,scope.xz,0.2,0.2,0.1,0.1)
            texture(beam_texture)
            projectUV(1)
#-------------------Veranda--------------------#
X -->
          primitiveCube()
          setupProjection(0, scope.xy, rand(1.5,2), rand(1.5,2), rand(1.5,2), rand(1.5,2))
          projectUV(0)
          set(material.bumpmap,veranda_texture)
          texture(veranda_texture)

Veranda -->
          comp(f) { bottom : X | side : X }
```

Annex 5: CGA code for vegetation models

```
#-------------------Attributes--------------------#
import Dist:"/ESRI.lib/rules/Plants/Plant_Distributor.cga"
import Plant:"/ESRI.lib/rules/Plants/Plant_Loader.cga"
grass               = "facade_textures/grass.png"
#----------------Starting Rules------------------#
Lot -->
          Bushes
          Grass
#------------------Vegetation--------------------#
Bushes -->
          set(Dist.Density, 2)              // Overgrown Density
          set(Dist.Mix, "Bush")             // Custom Mix of Species to Replicate Lobatse
Greenery
          Dist.Generate

Grass -->
          texture(grass)
```

Annex 6: CGA code for vegetable models

```
#--------------------Models----------------------#
attr type                              = rand(1,3)

const millet                           = "facades_objects/corn.obj"
millet_tex                             = "facade_textures/corn.jpg"
#----------------Starting Rules------------------#
Lot -->
```

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```
        Distribute
#------------------Millet Rows-------------------#
Distribute -->
        split(x){ ~1.8 : split(z){~1.98 : Millet}*}*
#-----------------------Millet-----------------------#
Millet -->
        i(millet)
        r(scopeOrigin, 90, rand(0,30), 0)
        s('0.8,'1.6,'1.8)
        t(rand(0.2,0.7), 0, 0)
        color("#F0F873")
        texture(millet_tex)
```

Annex 7: CGA code for wooden kraal model

```
#------------------Attributes-------------------#

attr height                              = 2.5


beam_texture                    = fileRandom("*facade_textures/Plank_v*.png")

#----------------Starting Rules------------------#

LotInner -->

         Lot


Lot -->

        offset(0.6) A

#--------------------Border----------------------#

A -->

        comp(f) { 1 : NIL | border : extrude(world.up, height) Fence }

#--------------------Beams----------------------#

GenericBeam -->

        primitiveCylinder(16, rand(0.05,0.07), height)

        r(0,rand(-5,10),0)

        setupProjection(0,scope.xz,0.2,0.2,0.1,0.1)

        texture(beam_texture)

         projectUV(1)


 Fence -->

        split(x) { ~ 0.2 : GenericBeam }*
```

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Annex 8: CGA code for cattle models

```
#--------------------Models----------------------#
attr cattle                        = rand(2,4)

const cow1                              = "facades_objects/cow1.FBX"
const cow2                              = "facades_objects/cow2.fbx"

hide1                                   = "facade_textures/cow_hide1.png"
hide2                                   = "facade_textures/cow_hide2.jpg"
#----------------Starting Rules------------------#
Lot -->
        Distribute
#-----------------Scatter Cows-------------------#
Distribute -->
        //offset( -4, inside)
        //scatter(surface, cattle, uniform) {Cows}

        split(x){ ~1.2 : split(z){~1.2 : Cows | ~3 : NIL}*
                                | ~5 : NIL}*
#---------------------Cows----------------------#
Cow1 -->
        i(cow1)
        r(scopeOrigin, 0, rand(180, 360), 0)

        t(rand(0.1, 1), 0, 0)
        s(0.7, 1.8, 2.4)
        texture(hide1)

Cow2 -->
        i(cow2)
        r(scopeOrigin, 0, rand(30, 90), 0)
         color("#FFFFFF")
        texture(hide2)
        projectUV(1)
        t(rand(0.1, 1), 0, 0)
        s(0.7, 1.8, 2.4)

Cows -->
        60% : Cow1
        else : Cow2
```

Annex 9: CGA code for midden models

```
#-----------------Attributes-------------------#
dirt                        = "facade_textures/Dirt.jpg"
#----------------Starting Rules------------------#
Lot -->
        Midden
        softenNormals(180)
#--------------------Midden----------------------#
Midden -->
```

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```
          roofHip(rand(6,9))
          setupProjection(0,scope.xz, rand(1, 1.5), rand(1, 1.5), rand(1, 1.5), rand(1, 1.5))
          set(material.bumpmap,dirt)
          projectUV(0)
          texture(dirt)
```

Annex 10: CGA code for grain bin models (main structure)

```
#------------------Attributes--------------------#
beam_texture                    = fileRandom("*facade_textures/Plank_v*.png")
#----------------Starting Rules-------------------#
Lot -->
          BinStructure
#----------------------Bin-----------------------#
BinStructure -->
          primitiveSphere(6, 8, 2) BinShape

BinShape -->
          t(0,0.5,0)
          comp(f) {bottom : BinBeam}

Beams -->
          primitiveCylinder(14,0.02, rand(4, 5))
          setupProjection(0,scope.xz,0.2,0.2,0.1,0.1)
          r(0,rand(-5,10),0)
          texture(beam_texture)
          projectUV(0)

 BinBeam -->
          split(x) {0.15 : Beams}*
```

Annex 11: CGA code for grain bin models (supportive beams)

```
#------------------Attributes--------------------#
beam_texture                    = fileRandom("*facade_textures/Plank_v*.png")
#----------------Starting Rules------------------#
LotInner -->
          Lot

Lot -->
          offset(0.1) A
#--------------------Border----------------------#
A -->
          comp(f) { border : extrude(world.up, 1) Support }
#--------------------Beams----------------------#
GenericBeam -->
          primitiveCylinder(16, 0.02, 1)
          setupProjection(0,scope.xz,0.2,0.2,0.1,0.1)
          texture(beam_texture)
          projectUV(1)
```

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```
Ring -->
	primitiveCylinder(16, 0.02, 0.4)
	r(90,90,90)
	setupProjection(0,scope.xz,0.2,0.2,0.1,0.1)
	texture(beam_texture)
	projectUV(1)

Support -->
	split(y) {0.9 : GenericBeam | 0.1 : Ring}
```

Annex 12: CGA code for grindng stone models

```
#-------------------Attributes--------------------#
stone                  = "facade_textures/rock_05_diff_1k.jpg"
const gs1              = "facades_objects/manual_grindstone.obj"

#-----------------Starting Rules-----------------#
Lot -->
	GrindingStone
	//Pot
#----------------Grinding Stone-----------------#
GrindingStone -->
	i(gs1)
	r(180, rand(0, 45), 0)
	t(-0.1,-0.14,-0.5)
	s('rand(1.7, 2.1),'rand(1.7, 2.1),'rand(1.7, 2.1))
	texture(stone)
	setupProjection(0, scope.xz, rand(0.7,0.9), rand(0.7,0.9), rand(0.7,0.9), rand(0.7,0.9))
	projectUV(0)
	set(material.bumpmap,stone)
```

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Annex 13: University of Pretoria Ethics Clearance

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Office of the Dean: Faculty of Natural and Agricultural Sciences

17 December 2020

Attention: The Faculty of Natural and Agricultural Sciences Ethics Committee

RE: Application for ethical clearance, reference number NAS288/2020

Title: Using Story Mapping and 3D visualization for Learning About Southern African Pre-colonial History and Urbanism in Space and Time: A Case Study for Seoke, Capital of the Bangwaketse.

This is to confirm support for the above application. I look forward to hearing about the outcomes of this novel approach.

Regards

PBloomer

Prof Paulette Bloomer
Deputy Dean: Teaching and Learning
Faculty of Natural and Agricultural Sciences

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www.up.ac.za

Kantoor van die Dekaan: Fakulteit Natuur- en Landbouwetenskappe
Ofisi ya Hlogo ya Lefapha: Lefapha la Disaense tša Tlhago le Temo

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Annex 14: University of Witwatersrand Research Permissions

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

OFFICE OF THE DEPUTY REGISTRAR

31 March 2021

Brenda-Ai Maina
Student number (16003382)
MSc Geoinformatics
University of Pretoria

TO WHOM IT MAY CONCERN

"Using Story Mapping and 3D visualization for Learning About Southern African Pre-colonial History and Urbanism in Space and Time: A Case Study for Seoke, Capital of the Bangwaketse"

This letter serves to confirm that the above project has received permission to be conducted on University premises, and/or involving staff and/or students of the University as research participants. In undertaking this research, you agree to abide by all University regulations for conducting research on campus and to respect participants' rights to withdraw from participation at any time.

If you are conducting research on certain student cohorts, year groups or courses within specific Schools and within the teaching term, permission must be sought from Heads of School or individual academics.

Ethical clearance has been obtained. Protocol number: (**NAS288/2020**)

Research Commencement: (06 April 2021)

Nicoleen Potgieter
University Deputy Registrar

Private Bag 3, WITS, 2050, South Africa | T +27 11 717 1204/8 | E nicoleen.potgieter@wits.ac.za | www.wits.ac.za
IYUNIVESITHI YASEWITWATERSRAND | YUNIVESITHI YA WITWATERSRAND
100 1922 2022

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Annex 15: Seoke Story Map Usability Questionnaire

Student Consent Form for Participants
Dear Participant

We invite you to take part in this survey to find out about your experiences and opinions about an exploratory digital environment for learning about a pre-colonial Southern African settlement. The information gathered through this survey will be used to learn about the use of a digital exploratory environment as a learning and teaching tool to educate non-experts about pre-colonial African history and urbanism.

This information page is intended to help you to decide whether you would like to participate in the study. Before you agree to participate, please read the following to fully understand what is involved.

Part of this study is an anonymous survey about the participants experience and opinions of the Story Map. No identifiable personal details such as your name will be collected. Any answers given in the survey will be kept completely confidential. As such, please answer the questionnaire as honestly as possible.

Your participation is completely voluntary. You may choose to not participate or to stop participating at any time, and there will be no negative consequences for your choice. Consent cannot, however, be withdrawn after the questionnaire has been submitted. This is because since no personal detail will be collected, we will not be able to trace the submission.

Students enrolled in certain modules will be awarded professional activity marks for their participation. Please ask your lecturer to learn if you are eligible for professional activity marks.

This study has been approved by the Research Ethics Committee of the Faculty of Natural and Agricultural Sciences (tel: 012 420 4356).

The results of the survey may be published in the media and/or an academic journal. Individual participants will not be identified in these circumstances. A summary of the findings of the survey will be made available to you on request.

If you have questions or comments about the study or any related topics please contact Brenda Maina at brenda.maina@tuks.co.za.

By clicking 'Next', you agree to the above terms and provide your consent to use your submission in the study.

Thank you.

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Gender

- ◯ Male
- ◯ Female
- ◯ Non-binary
- ◯ Prefer not to say
- ◯ Self-describe: ____

Age

*Enter Text*____

Current Academic Year

- ◯ 1st year
- ◯ 2nd year
- ◯ 3rd year
- ◯ 4th year/Honours
- ◯ Masters
- ◯ PhD
- ◯ I am not a student

Which university do you currently attend?

- ◯ University of Botswana
- ◯ University of KwaZulu-Natal
- ◯ University of Pretoria
- ◯ University of Witwatersrand
- ◯ Other ____
- ◯ I do not attend an university

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For which course are you currently registered?

- ◯ BA Archaeology
- ◯ BA Geography
- ◯ BA History
- ◯ BSc Archaeology
- ◯ BSc Environmental Science
- ◯ BSc Geoinformatics
- ◯ BSc Geography
- ◯ BSc Meteorology
- ◯ Other ____
- ◯ I am not a student

How comfortable are you with English?

- ◯ Very uncomfortable
- ◯ Uncomfortable
- ◯ Neutral
- ◯ Comfortable
- ◯ Very comfortable

How comfortable are you with using a computer?

- ◯ Very uncomfortable
- ◯ Uncomfortable
- ◯ Neutral
- ◯ Comfortable
- ◯ Very comfortable

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How many hours of sleep did you get last night?

- ◯ 3 or less
- ◯ 3 - 5
- ◯ 5 - 7
- ◯ 7 - 9
- ◯ 9+

Are you colour-blind? If so, select a type.

- ◯ Deuteranomaly (green looks more red)
- ◯ Protanomaly (red looks more green)
- ◯ Protanopia (red/green look similar)
- ◯ Deuteranopia (red/green look similar)
- ◯ Tritanomaly (blue/green and yellow & red look similar)
- ◯ Tritanopia (blue/green, purple/red and yellow/pink look similar)
- ◯ I am not colour-blind

Are you currently wearing contact lenses or prescription glasses?

- ◯ Contact lenses
- ◯ Prescription Glasses
- ◯ No

Did you take any of these subjects in High School? *(choose one or more)*

- ☐ Geography
- ☐ History
- ☐ Neither

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Have you completed a module covering the following topics at university? *(choose one or more)*

- ☐ Physical Geography
- ☐ Urban Geography
- ☐ GIS or Remote Sensing
- ☐ Southern African Pre-colonial History
- ☐ Archaeology
- ☐ None of the above

What is your interest level in the topic of Southern African Pre-colonial History?

- ○ No interest
- ○ Short-term interest (during the survey)
- ○ Casual interest
- ○ Somewhat interested
- ○ Very interested

What is your experience with Story Maps?

- ○ I have no experience
- ○ I have heard of Story Maps
- ○ I have used (i.e. read or studied) a Story Map before
- ○ I have created my own Story Map

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What is your experience with 3D models?

- ◯ I have no experience
- ◯ I have heard of 3D modelling
- ◯ I have used 3D models
- ◯ I have created 3D models

What is your experience with Google Earth?

- ◯ I have no experience
- ◯ I have heard of Google Earth
- ◯ I have used Google Earth

How much do you know about Southern African pre-colonial settlements (i.e. Mapungubwe, Great Zimbabwe etc…)?

- ◯ None at all
- ◯ A little
- ◯ A moderate amount
- ◯ A lot
- ◯ A great deal

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Please answer the following questions about the usability of the platform.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
I think that I would like to use the story map frequently	○	○	○	○	○
I found the story map to be unnecessarily complex.	○	○	○	○	○
I think that the story map was easy to use.	○	○	○	○	○
I think that I would need the support of a technical person to be able to use the story map.	○	○	○	○	○
I found that the different sections of the story map were well integrated.	○	○	○	○	○
I thought there was too much inconsistency in the story map.	○	○	○	○	○
I think people would learn how to use the story map very quickly.	○	○	○	○	○
I found that the story map was too cumbersome to use.	○	○	○	○	○
I felt very confident while using the story map.	○	○	○	○	○
I need to learn a lot of things before I could get going with the story map.	○	○	○	○	○
I felt that the information in the story map felt complete.	○	○	○	○	○
I felt that there were information gaps in the story map.	○	○	○	○	○

Please answer the following questions about the 3D visualization in the Story Map.

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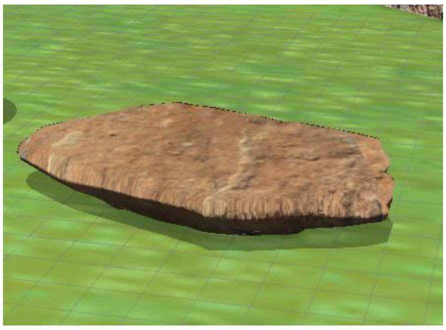
Where was waste/refuse disposed?


Midden


Grain bin


Grinding stone

How confident are you?

	0 10 20 30 40 50 60 70 80 90 100
% Confidence ()	

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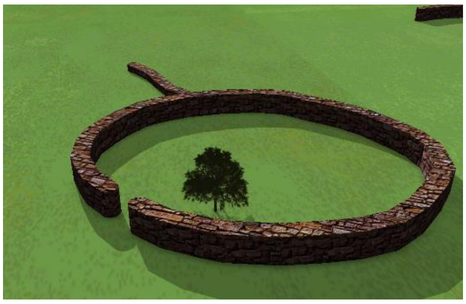
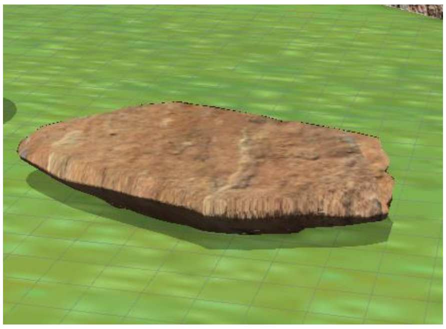
What was used to store produce or grain?



○ Wall

○ Grain bin



○ Grinding stone

How confident are you?

	0 10 20 30 40 50 60 70 80 90 100
% Confidence ()	

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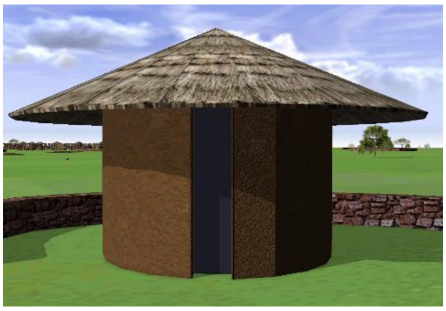
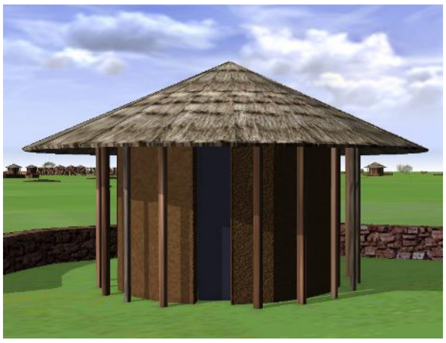
Identify the dwelling that is most like what you saw in the 3D model.

○ Dwelling1



○ Dwelling2

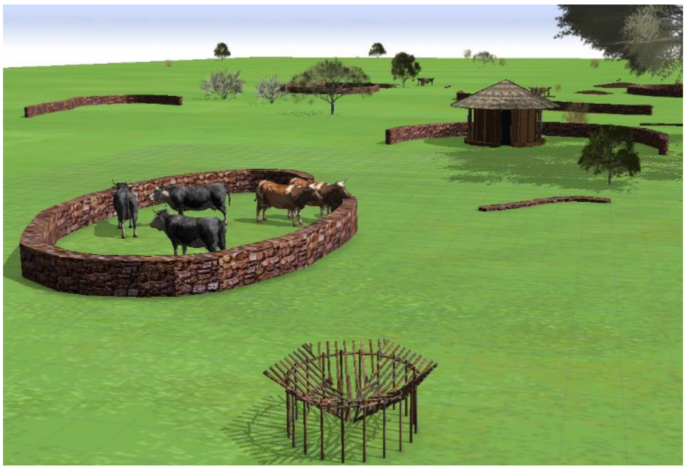


○ Dwelling3

How confident are you?

	0 10 20 30 40 50 60 70 80 90 100
% Confidence ()	

Which of the following words best describe the objects in this image? *(choose one or more)*



- [ ] Stone Walls
- [ ] Grinding Stone
- [ ] Dwelling
- [ ] Pot
- [ ] Cattle Kraal
- [ ] Midden
- [ ] Grain Bin

How confident are you?

	0 10 20 30 40 50 60 70 80 90 100
% Confidence ()	

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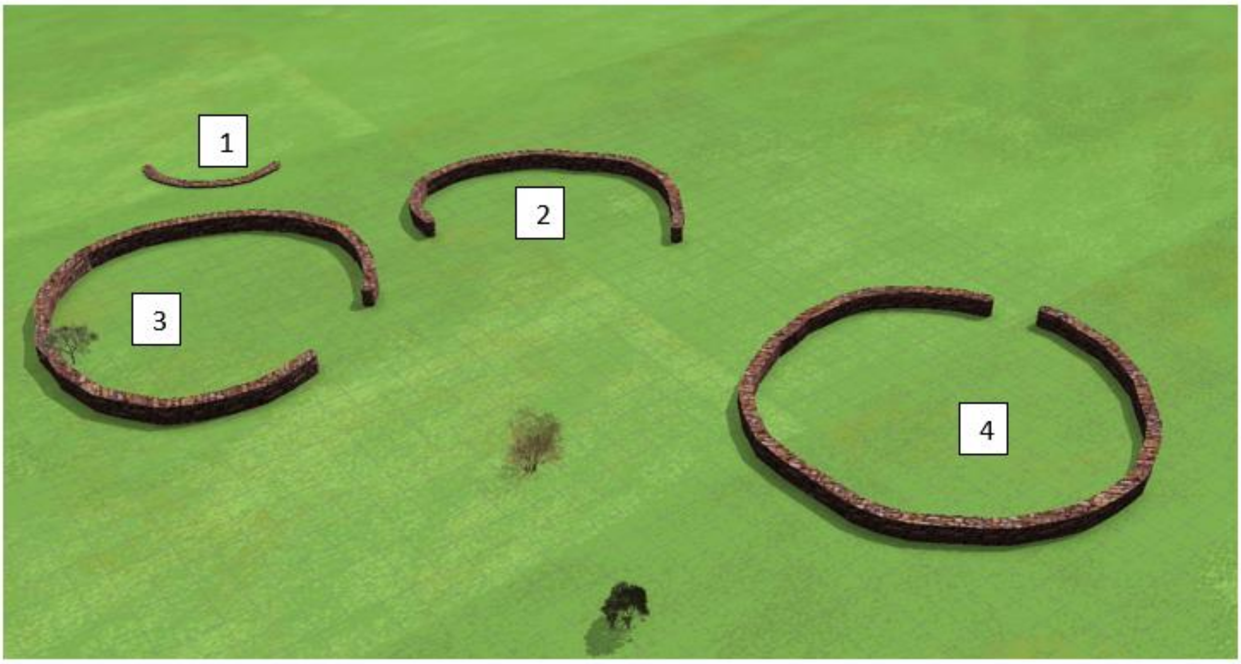
In this image, where could a dwelling have been located? *(choose one or more)*



- ☐ 1
- ☐ 2
- ☐ 3
- ☐ 4

How confident are you?

	0 10 20 30 40 50 60 70 80 90 100
% Confidence ()	

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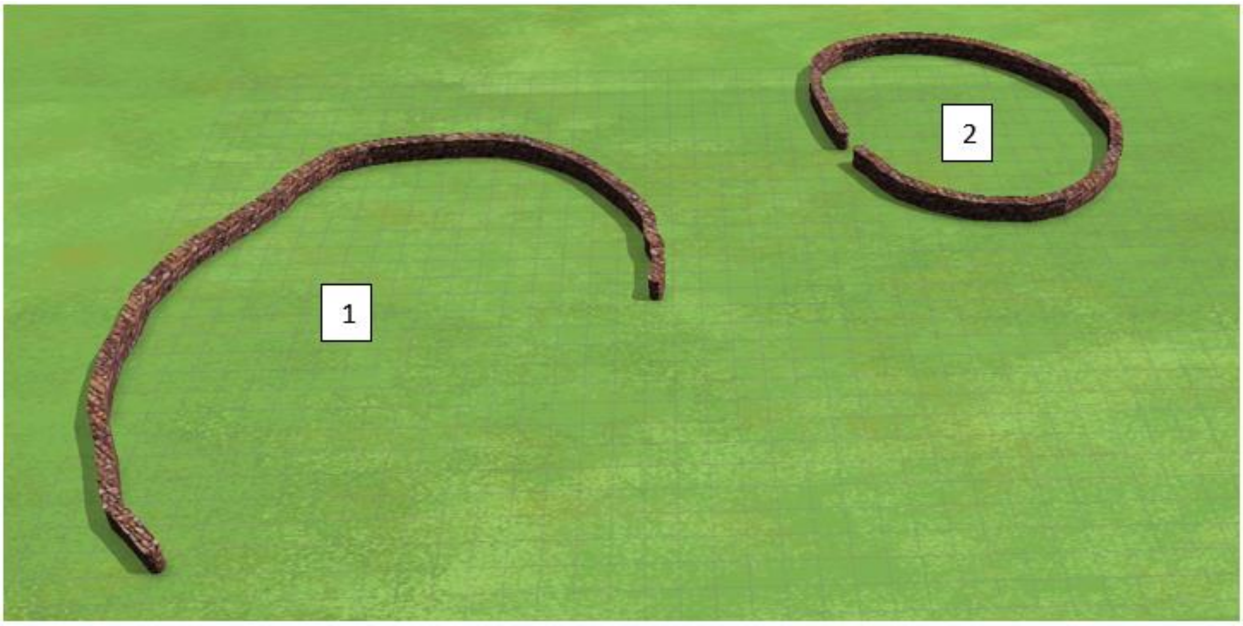
In this image, where would livestock (cattle, goats or sheep) be kept? *(choose one or more)*



- ☐ 1
- ☐ 2

How confident are you?

	0	10	20	30	40	50	60	70	80	90	100
% Confidence ()											

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Please answer the following questions about the value of the platform.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
The 3D model helped me understand the text from the Story Map better.	○	○	○	○	○
The 3D model helped me to imagine what it was like to be in a pre-colonial Southern African settlement.	○	○	○	○	○
The 3D model made learning about Seoke more engaging.	○	○	○	○	○
I think this is an innovative way to learn about Seoke.	○	○	○	○	○
Virtual field trips for Cultural Heritage Sites such as Seoke are valuable.	○	○	○	○	○

What made the 3D model attractive? *(choose one or more)*

- ☐ Graphics and realism
- ☐ Interactiveness
- ☐ It was something new
- ☐ Easy to navigate
- ☐ It was different from other visualizations I have seen in the past

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How organic/realistic does the model look to you?

- ○ Not at all
- ○ A little
- ○ A moderate amount
- ○ A lot
- ○ A great deal

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Does the 3D model resemble a settlement you have visited or lived in?

- Not at all
- A little
- A moderate amount
- A lot
- A great deal

Do you feel like you learned something about Southern African pre-colonial settlements?

- Not at all
- A little
- A moderate amount
- A lot
- A great deal

Did this experience change any prior perceptions about pre-colonial Southern Africa?

- Not at all
- A little
- A moderate amount
- A lot
- A great deal

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Would you agree with the statement that a settlement like Seoke could be considered a pre-colonial Southern African city?

- ◯ Not at all
- ◯ A little
- ◯ A moderate amount
- ◯ A lot
- ◯ A great deal

Was the experience enlightening?

- ◯ Not at all
- ◯ A little
- ◯ A moderate amount
- ◯ A lot
- ◯ A great deal

Please rate your enjoyment level while using the Story Map and 3D model.

- ◯ Extremely bad
- ◯ Somewhat bad
- ◯ Neutral
- ◯ Somewhat good
- ◯ Extremely good

If you have any additional comments, please add them below.

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Annex 16: Seoke Story Map Eye-tracking Questionnaire

Student Consent Form for Participants

Dear Participant

We invite you to take part in this survey to find out about your experiences and opinions about an exploratory digital environment for learning about a pre-colonial Southern African settlement. The information gathered through this survey will be used to learn about the use of a digital exploratory environment as a learning and teaching tool to educate non-experts about pre-colonial African history and urbanism.

This information page is intended to help you to decide whether you would like to participate in the study. Before you agree to participate, please read the following to fully understand what is involved.

Part of this study is an anonymous survey about the participants experience and opinions of the Story Map. No identifiable personal details such as your name will be collected. Any answers given in the survey will be kept completely confidential. As such, please answer the questionnaire as honestly as possible.

Your participation is completely voluntary. You may choose to not participate or to stop participating at any time, and there will be no negative consequences for your choice. Consent cannot, however, be withdrawn after the questionnaire has been submitted. This is because since no personal detail will be collected, we will not be able to trace the submission.

Students enrolled in certain modules will be awarded professional activity marks for their participation. Please ask your lecturer to learn if you are eligible for professional activity marks.

This study has been approved by the Research Ethics Committee of the Faculty of Natural and Agricultural Sciences (tel: 012 420 4356).

The results of the survey may be published in the media and/or an academic journal. Individual participants will not be identified in these circumstances. A summary of the findings of the survey will be made available to you on request.

If you have questions or comments about the study or any related topics please contact Brenda Maina at brenda.maina@tuks.co.za.

By clicking 'Next', you agree to the above terms and provide your consent to use your submission in the study.

Thank you.

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Gender

- ◯ Male
- ◯ Female
- ◯ Non-binary
- ◯ Prefer not to say
- ◯ Self-describe: ____

---

*

Age

Enter Text

Current Academic Year

- ◯ 1st year
- ◯ 2nd year
- ◯ 3rd year
- ◯ 4th year/Honours
- ◯ Masters
- ◯ PhD
- ◯ I am not a student

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For which course are you currently registered?

- ◯ BSc Environmental Science
- ◯ BSc Geoinformatics
- ◯ BSc Geography
- ◯ BSc Meteorology
- ◯ Other ____
- ◯ I am not a student

How comfortable are you with English?

- ◯ Very uncomfortable
- ◯ Uncomfortable
- ◯ Neutral
- ◯ Comfortable
- ◯ Very comfortable

How comfortable are you with using a computer?

- ◯ Very uncomfortable
- ◯ Uncomfortable
- ◯ Neutral
- ◯ Comfortable
- ◯ Very comfortable

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How many hours of sleep did you get last night?

- 3 or less
- 3 - 5
- 5 - 7
- 7 - 9
- 9+

Are you colour-blind? If so, select a type.

- Deuteranomaly (green looks more red)
- Protanomaly (red looks more green)
- Protanopia (red/green look similar)
- Deuteranopia (red/green look similar)
- Tritanomaly (blue/green and yellow & red look similar)
- Tritanopia (blue/green, purple/red and yellow/pink look similar)
- I am not colour-blind

Are you currently wearing contact lenses or prescription glasses?

- Contact lenses
- Prescription Glasses
- No

Did you take any of these subjects in High School? *(choose one or more)*

- Geography
- History
- Neither

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Have you completed a module covering the following topics at university? *(choose one or more)*

- ☐ Physical Geography
- ☐ Urban Geography
- ☐ GIS or Remote Sensing
- ☐ Southern African Pre-colonial History
- ☐ Archaeology
- ☐ None of the above

What is your interest level in the topic of Southern African Pre-colonial History?

- ○ No interest
- ○ Short-term interest (during the survey)
- ○ Casual interest
- ○ Somewhat interested
- ○ Very interested

What is your experience with 3D models?

- ○ I have no experience
- ○ I have heard of 3D modelling
- ○ I have used 3D models
- ○ I have created 3D models

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What is your experience with Google Earth?

- ◯ I have heard of Google Earth
- ◯ I have used Google Earth
- ◯ I have no experience

How much do you know about Southern African pre-colonial settlements (i.e. Mapungubwe, Great Zimbabwe etc…)?

- ◯ None at all
- ◯ A little
- ◯ A moderate amount
- ◯ A lot
- ◯ A great deal

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Please answer the following questions about the 3D visualization in the Story Map.

Where was waste disposed?


○ Midden

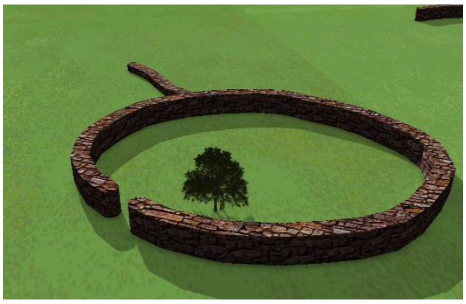

○ Grain bin


○ Grinding stone

How confident are you?

	0	10	20	30	40	50	60	70	80	90	100
% Confidence ()											

What was used to store produce or grain?

- ○  Wall
- ○  Grain bin
- ○  Grinding stone

How confident are you?

	0 10 20 30 40 50 60 70 80 90 100
% Confidence ()	

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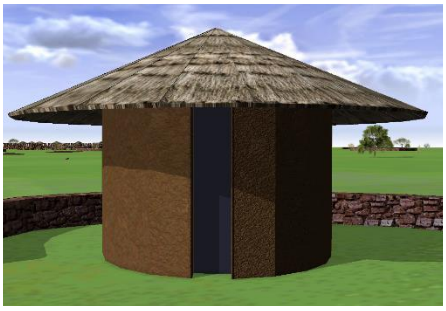
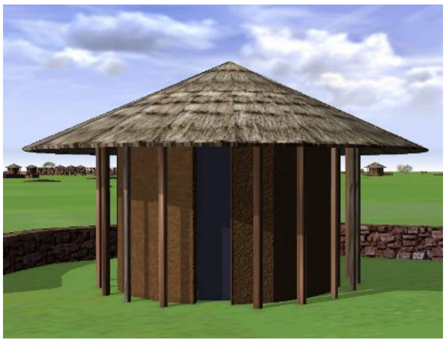
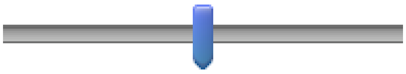
Identify the dwelling that is most like what you saw in the 3D model.

○  Dwelling1

○  Dwelling2

○  Dwelling3

How confident are you?

	0 10 20 30 40 50 60 70 80 90 100
% Confidence ()	

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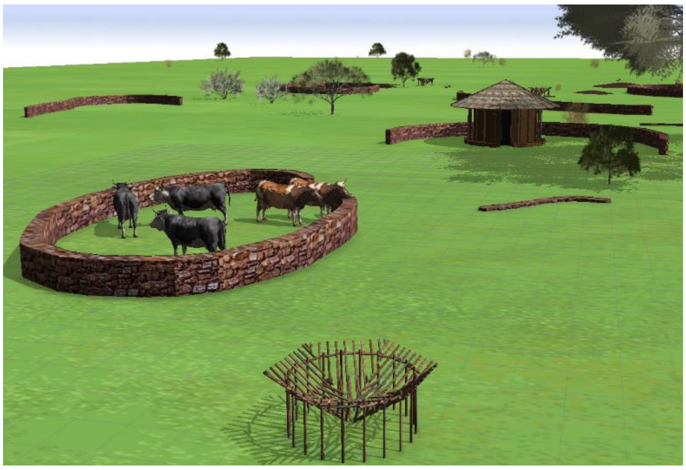
Which of the following words best describe the objects in this image? *(choose one or more)*



☐ Stone Walls

☐ Grinding Stone

☐ Dwelling

☐ Pot

☐ Cattle Enclosure

☐ Midden

☐ Grain Bin

How confident are you?

	0 10 20 30 40 50 60 70 80 90 100
% Confidence ()	

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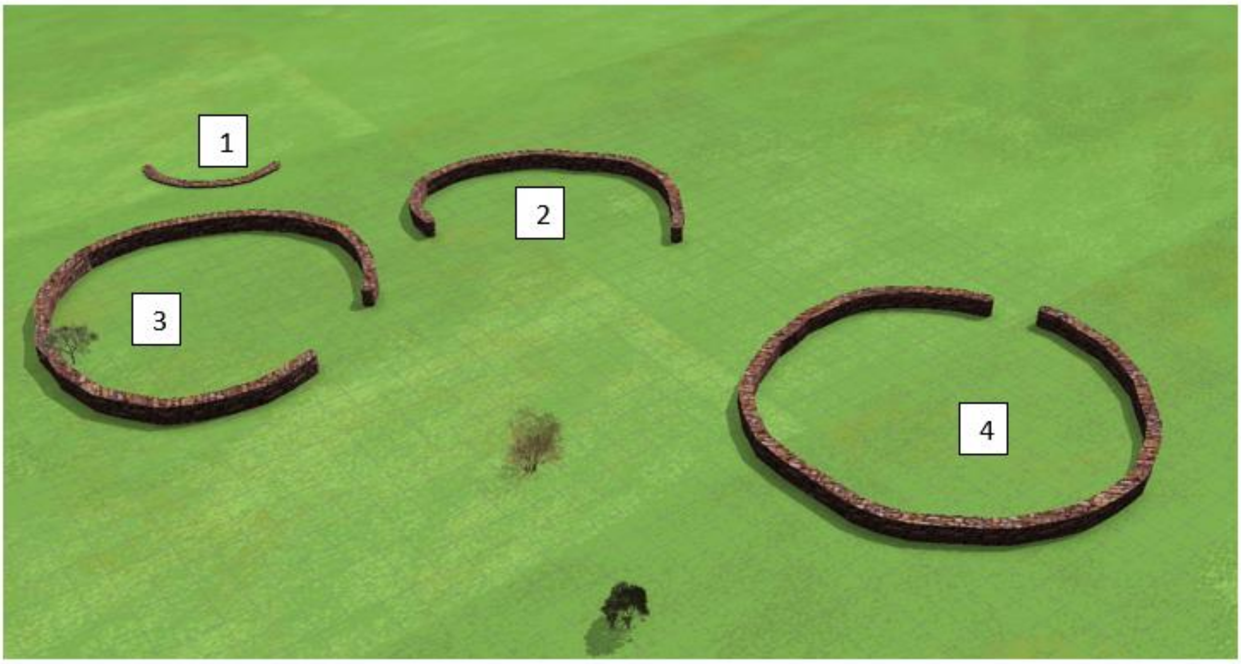
In this image, where could a dwelling have been located? *(choose one or more)*



- [ ] 1
- [ ] 2
- [ ] 3
- [ ] 4

How confident are you?

	0 10 20 30 40 50 60 70 80 90 100
% Confidence ()	

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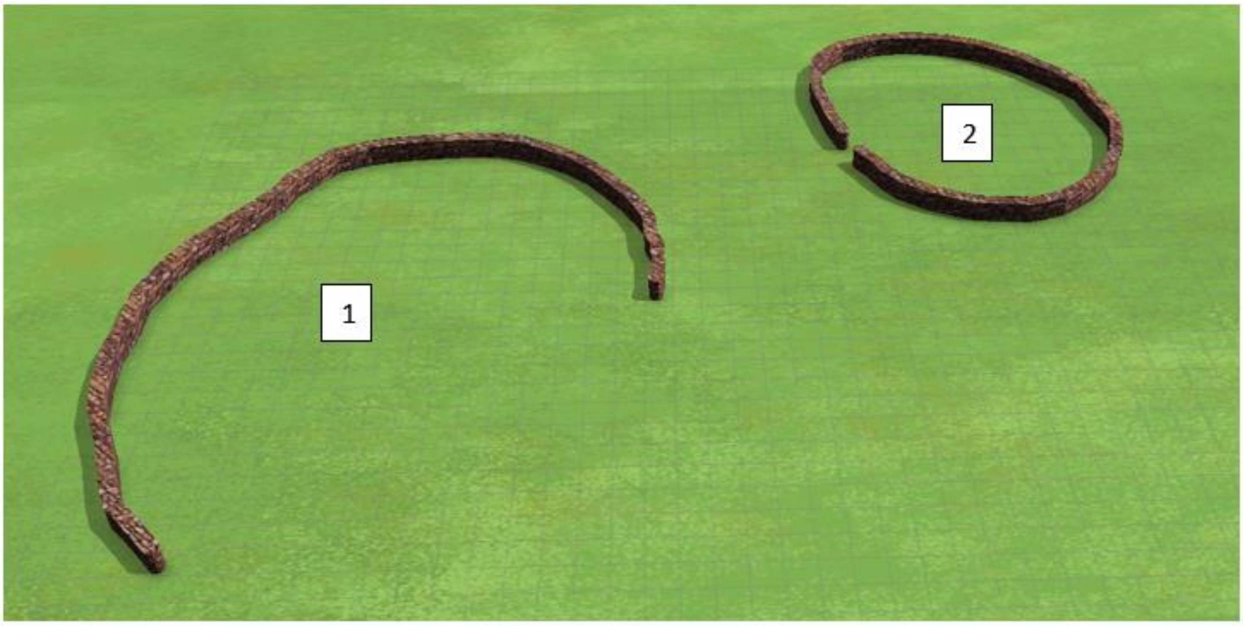
In this image, where would livestock (cattle, goats or sheep) be kept? *(choose one or more)*



☐ 1

☐ 2

How confident are you?

	0 10 20 30 40 50 60 70 80 90 100
% Confidence ()	

What made the 3D visualization attractive? *(choose one or more)*

☐ Graphics and realism

☐ It was something new

☐ Easy to navigate

☐ It was different from other visualizations I have seen in the past

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How organic/realistic does the model look to you?

- Not at all
- A little
- A moderate amount
- A lot
- A great deal

Does the 3D model resemble a settlement you have visited or lived in?

- Not at all
- A little
- A moderate amount
- A lot
- A great deal

Do you feel like you learned something about Southern African pre-colonial settlements?

- Not at all
- A little
- A moderate amount
- A lot
- A great deal

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Did this experience change any prior perceptions about pre-colonial Southern Africa?

- Not at all
- A little
- A moderate amount
- A lot
- A great deal

Would you agree with the statement that a settlement like Seoke could be considered a pre-colonial Southern African city?

- Not at all
- A little
- A moderate amount
- A lot
- A great deal

Was the experience enlightening?

- Not at all
- A little
- A moderate amount
- A lot
- A great deal

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Please rate your enjoyment level while using the Story Map and 3D model.

- ○ Extremely bad
- ○ Somewhat bad
- ○ Neutral
- ○ Somewhat good
- ○ Extremely good

If you have any additional comments, please add them below.

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