Innovations in Machine Learning: A Case Study of the Fabricius Workbench

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Research

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Submitted 23 March 2021

Declaration

This work has not previously been submitted for a degree or diploma in any university. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made in the thesis itself.

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23 March 2021

Abstract

This thesis investigates how the open-source computer program called the *Fabricius Workbench* complements the process of translating Hieroglyphic Egyptian texts. The *Workbench*, developed by Google, Ubisoft, and Psycle Interactive, employs machine learning in an attempt to speed up translation, as has been successfully carried out for other - even ancient - languages. The *Workbench* utilises machine learning to identify images of Egyptian hieroglyphs. Users can edit a facsimile layer and reconstruct damaged sections of text. The program also suggests words to assist the user in formulating their translation. *Workbench* project files are stored in a format that is easily shared and edited. By employing eight volunteer Egyptologists of varying skill levels to produce a translation using the *Workbench*, this thesis evaluated whether there are elements of the program that demonstrate how digital tools might improve the translation process. After analysing the outcomes of the case study by considering the strengths, weaknesses, opportunities, and threats (SWOT) of the program, focusing on user experience, initial expectations of the *Workbench* had to be reconsidered. The program as it stands would require significant improvements to become a viable tool for Egyptologists. As such, focusing on the individual components of the *Workbench* would offer earlier rewards and develop a community of users who could demonstrate academic outcomes, thus encouraging further development. Therefore, the program either needs to split into its smaller components or pivot to a tool within a pedagogical program that would sustain the established userbase. Since the *Workbench* demonstrates that digital technology can be used to capture, manipulate, and analyse hieroglyphic information, it is suggested that students of Hieroglyphic Egyptian could be presented with activities and exercises that show them how to encode and mark up hieroglyphs in order to contribute to the

amount of digital textual material of the Ancient Egyptian language available worldwide.

Acknowledgements

I would like to thank my supervisors Dr Shawn Ross, Dr Alex Woods, Dr Brian Ballsun-Stanton, and Dr Camilla Di Biase-Dyson for their guidance and support throughout this thesis; Alex Fry of Psycle Interactive for his knowledge and patience; and Ubisoft and Google Arts and Culture for their collaboration and enthusiasm for creating digital tools for the Egyptological community. I would also like to thank Dr Brian Ballsun-Stanton, as well as my friend Rafael Da Silva Chaves, for helping me produce such a beautifully formatted thesis.

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Chapter 1

Introduction

Translating texts written in ancient Egyptian hieroglyphic script is a valuable aspect of studying ancient Egyptian culture, yet it can be tedious and time-consuming. The process involves consulting dictionaries, grammars, and online databases and corpora of textual and hieroglyphic material. The translator effectively deconstructs the ancient text in order to reassemble it in their chosen modern language.[1] Egyptologists learn how to identify the functions of hieroglyphs, their phonetic values, semantic meanings, and how they interact with the hieroglyphs around them.

One of the first steps to translating an Hieroglyphic Egyptian text is to identify what hieroglyphs are represented. With the ability of computers to identify images, is it possible for a computer to identify the hieroglyphs for us? In 2015, a study showed that computers had achieved a level of visual recognition that surpassed human performance.[2] The study demonstrated that artificial intelligence (AI) allowed the computer to distinguish between different breeds of dogs in digital images at a higher rate of accuracy than humans.[3] The idea that it might be possible for Egyptologists to use computers to identify hieroglyphs and thus potentially speed up the translation process inspired the gaming company Ubisoft to develop a computer program called the *Hieroglyphics Initiative*.[4] It was designed to help Egyptologists employ a digital approach to

[1] Due to the subject and limited scope of this thesis, I will be focusing on English translations only.
[2] He *et al.* 2015, 9.
[3] He *et al.* 2015, 9.
[4] Psycle Interactive 2021.

translating Hieroglyphic Egyptian texts. This tool, later called the '*Workbench*' (henceforth *Fabricius Workbench* or the *Workbench*), forms part of the *Fabricius* platform released by Google Arts and Culture in July of 2020.

This thesis investigated to what extent the *Workbench* could improve or enhance the translation of Hieroglyphic Egyptian texts through a case study.[5] This case study explored how a sample of Egyptologists responded to using this new tool. Although the case study found that the *Workbench* actually impeded the translation process rather than made it easier or faster, it prompted a discussion on what digital tools might be developed in the near future for the Egyptological community.

Although computers have become extremely advanced, general intelligence and reasoning remain exclusively human traits. while a computer can identify a dog breed from an image, this is not true interpretation. The machine has been trained using thousands of images of dogs and is therefore able to 'see' a configuration of pixels and 'think' 'this is a pug', but it has no conceptual understanding of what a pug is.[6] In the same way, a computer may also be able to recognise patterns of pixels and assign them a 'Gardiner code' (see *Excursus 1*), however, the program does not have any concept of what an hieroglyph is. Thus, the relationship between a researcher and the computer program they are using can be viewed as that between a human and their digital toolkit. Such is the case with the focus of this project: the *Fabricius Workbench* (see *Excursus 2*).

AI is a powerful tool that has revolutionised research, the economy, and how humans interact with the world around them more generally.[7] This thesis provides an example of how AI's relationship to research in the humanities can lead to further digital-born research questions. With modern computer programs like *Google Translate* and *DeepL*, AI – and more specifically machine learning – has proven to be a potential pathway for harnessing the processing power of computers to study language.[8] While progress in the field of AI generates the fear

[5] View the ***Fabricius Workbench*** (Google Arts and Culture 2020d) and the Google Arts and Culture ***Fabricius* GitHub repository** (Grayston 2021).
[6] Guszcza, Evans-Greenwood and H. Lewis 2017, 11.
[7] Guszcza, Evans-Greenwood and H. Lewis 2017, 10.
[8] The Oxford English Dictionary defines *machine learning* as 'the capacity of computers to learn and adapt without following explicit instructions, by using algorithms and statistical models to analyse and infer from patterns in data' (Oxford English Dictionary 2020a); Karen Hao expresses the concept as simply 'find the pattern, apply the pattern' (Hao 2018); Groves and Mundt 2014,

that AI inspired innovations will replace a large portion of the workforce, when it comes to research, this technology has a number of benefits, specifically the focus on 'intelligence augmentation', where humans design machines that help them 'think better' and form a human-tool relationship.[9]

1.1 Research Questions

This state of affairs, involving the potential implementation of machine learning to the digital processing of hieroglyphs, the release of a computer program aimed at assisting Egyptologists achieve this implementation, and the fact that this program was created by non-Egyptologists, prompts the Egyptologist user to ask the following questions:

1. How useful is the *Fabricius Workbench* in translating Hieroglyphic Egyptian?
2. Are there improvements that can be made to the *Fabricius Workbench* that will make it more useful in translating Hieroglyphic Egyptian?
3. Are there aspects of the *Fabricius Workbench* that can be extracted, isolated and/or expanded upon as separate tools or projects that would be useful in translating Hieroglyphic Egyptian?
4. Are there aspects of the *Fabricius Workbench* that can be extracted, isolated and/or expanded upon as separate tools or projects that would be useful for collaboration among Egyptologists worldwide?
5. What are the interests of the stakeholders?
    a. Are they compatible or are there tensions?
    b. If so, what, if any, impact did these tensions have on the functionality of the final product?

The case study (see § 1.2 and § 3.3) conducted in this thesis was designed to respond to these questions.

113; Macketanz, Burchardt and Uszkoreit 2018; de Vries, Schoonvelde and Schumacher 2018, 118; Google 2021b; Google 2021a.

[9] Guszcza, Evans-Greenwood and H. Lewis 2017, 10; World Economic Forum 2016, 10.

In order to understand how the case study investigated how effectively the *Fabricius Workbench* enhanced the translation of Hieroglyphic Egyptian texts, it is important to understand how the Egyptian language and script evolved and how hieroglyphs are organised and categorised.

Excursus 1: The Egyptian Language, Script, and Gardiner's Sign List

The complex writing system of the ancient Egyptians is one of the oldest in the world and 'our understanding of it' is continuing to develop.[10] Ancient Egyptian-Coptic belongs to the Afroasiatic language family and while it shares commonalities with all branches of this family, is regarded as distinct.[11] The Egyptian language went through five main stages of development:[12]

- Old Egyptian (2600–2100 BCE)
- Middle Egyptian (2100–1600 BCE)
- Late Egyptian (1600–600 BCE)
- Demotic (650 BCE–5th century CE)
- Coptic (2nd century CE–11th century CE)

Written Egyptian during the pharaonic period was recorded in both hieroglyphic and hieratic scripts, which, although closely related, are not identical. For the purposes of this thesis, I will henceforth be focusing exclusively on the hieroglyphic script, of the Middle Egyptian stage, as the *Fabricius Workbench* was exclusively trained with this script.[13] Written Hieroglyphic Egyptian is comprised of a vast sign set, which numbered from several hundred signs in the earliest

[10] Allen 2013, xi.
[11] Allen 2010, 1.
[12] Allen 2010, 1; While these represent five distinct stages of development of the Egyptian language, it is important to note that these stages experience significant overlap and examples of writing in ancient Egypt has been dated as far back as 3250 BCE (Regulski 2016, 4); see also Dreyer 1998.
[13] Middle Egyptian, sometimes referred to as 'Classical Egyptian', was the spoken language of Egypt between 2100 and 1600 BCE and continued to be used as the language stage preferred when writing high-register texts using the hieroglyphic script.Allen 2010, 1 Due to this, Middle Egyptian is often what we think of when conjuring images of ancient Egyptian tombs and monuments that have drawn so many audiences around the world.

period to thousands in the Graeco-Roman Period.[14] To bring order to this set, Alan H. Gardiner proposed a system to group hieroglyphs in an organised and cohesive manner and in 1927, he published the resulting Sign List in his book *Egyptian Grammar: Being an Introduction to the Study of Hieroglyphs.*[15] The Sign List aims to 'enumerate the commonest hieroglyphs in Middle Egyptian' and is organised into 27 categories, based on the type of image represented by each family of hieroglyphs, such as *Birds*, *Mammals*, and *Buildings, Parts of Buildings*.[16] Each category has been assigned a letter, such as *Sect. G. Birds*, and each hieroglyph within a category has an associated number.[17] This designation is referred to as the Gardiner Code of an hieroglyph. Thus, Gardiner Code G43 𓅱 refers to hieroglyph 43 of the category G (Birds), which represents a quail chick and has the phonetic value of 'w'.[18]

In addition to identifying individual hieroglyphs, one must master other aspects of Egyptian script before approaching a translation. For example, it is crucial to ascertain the function of each hieroglyph (signs fall into three categories: ideograms/logograms, phonograms, and determinatives/classifiers), the direction of the text (which determines in what order the hieroglyphs are to be read), and how the hieroglyphs have been grouped (which helps indicate which signs belong to which words).[19] While I have previously highlighted that computers may be able to identify hieroglyphs through image recognition, we must consider whether a computer program would be capable of performing these other tasks necessary to produce a translation. We must consider whether a computer program would be capable of performing these and other (grammatical and lexicographical) tasks to assist in producing a translation. While hieroglyph identification is a necessary first step, it is also necessary (and more difficult) to group signs in a meaningful, machine legible way in order to facilitate translation.

[14] Loprieno 1995, 12.
[15] Gardiner 1927.
[16] Gardiner 1957, 438–548, 438–548, 458–461, 467–473, 492–498.
[17] Gardiner 1957, 438-441, 467.
[18] Gardiner 1957, 472; The longevity of Gardiner's system is reflected in the organisation of the Unicode character code tables, the alpha-numerical categorisation framework of which follows the Gardiner groupings (Unicode, Inc. 2021).
[19] Allen 2010, 2–7.

Excursus 2: Development and Testing of the Fabricius Workbench

According to Alex Fry, director at Psycle Interactive, the digital agency that developed the *Fabricius Workbench*, the initial challenge faced by the team was the lack of digital images of individual hieroglyphs, which are required to train any mahcine learning models.[20] As machine learning models require immense amounts of data to properly train, Ubisoft invited their *Assassin's Creed* players to help create a training dataset using Google's cloud database *Firebase*, which allowed over 80'000 drawings of approximately 800 different hieroglyphs to be collected in one night.[21]

Training on tracings produced by gamers was a proof of concept. However, it failed to train machine learning models to recognise Egyptian hieroglyphs consistently and accurately on degraded surfaces from photos. This was then insufficiently matchable with standardised examples of hieroglyphs produced from data provided by the Thesaurus Linguae Aegyptiae. Lacking in-house Egyptological experience, Psycle's choice of training data thus paired poorly with the examples chosen for this study and, significantly, the use-case envisioned for the *Workbench*. This choice was understandable from Psycle's perspective, due to the complexity and time required of annotating and tagging the immense image dataset required for training Hieroglyphic Egyptian machine learning models. A future doctoral project (or similar) involving Egyptologists and technologists devoted to developing a training dataset for such machine learning models would help projects like the *Fabricius Workbench* become viable digital tools for Egyptologists.

While early attempts to train the machine learning model called *Inception v3* proved unsuccessful, Psycle found some success with use of *Auto ML Vision*, which returned an accuracy rate of 77% correctly identified hieroglyphs in the top three predictions.[22] Psycle determined that this was an acceptable success rate, and thus the team were confident they could apply this process to the translation of Hieroglyphic Egyptian.

In order to determine where in the translation process machine learning could be integrated, Ubisoft identified three stages of translation: 'transcribing

[20] Google Cloud 2019.
[21] Google Cloud 2018, 1:27:00–1:30:00; Google Cloud 2019.
[22] Psycle Interactive 2020, 31:00–38:23.

individual glyphs, sequencing them, and the translating them'.[23] Ubisoft consulted with academics around the world in order to attempt the following: to 'understand how these researchers work and the tools they need, and then engage them in testing the tools and providing feedback'.[24]

Despite this, it does not appear that they performed extensive user acceptance testing for the program at that time. The case study conducted during this project, is the first user-based test of its kind. Specifically, it asked eight participants of varying levels of proficiency with Hieroglyphic Egyptian to engage with the *Workbench* in order to assess whether it is useful for Egyptologists, has the potential to be useful, or does not provide a meaningful addition to the process of translation as it currently stands.[25]

Dr Alex Woods of Macquarie University stated that the *Fabricius Workbench* 'provides a framework and set of purpose-built tools to digitally capture and analyse hieroglyphic data'.[26] She also points to the *Workbench's* potential to allow educators in Egyptology to integrate innovative technology into the teaching of Middle Egyptian, as well as provide 'opportunities for research collaboration and partnerships'.[27] No direct comment was made about the program's ability to assist in the translation process itself. In fact, both Dr Woods and I have tested the *Fabricius Workbench* by attempting to translate examples of ancient Egyptian hieroglyphic texts, and it became evident over time that the promise of a faster, more efficient translation process supported by digital tools was not upheld. Over the course of the case study, I shifted my initial conceptions of the program and readjusted my expectations. Rather than being a program designed to help scholars in their research, I would suggest that, with adjustments, a potential application of a program like the *Fabricius Workbench* would be teaching students of Egyptology how to encode Hieroglyphic data.[28]

Dr Woods' points that the *Fabricius Workbench* can 'capture and analyse

[23]Google Cloud 2019.
[24]Google Arts and Culture 2020a; Google Cloud 2019.
[25]The results of this case study will be shared directly with Psycle project director Alex Fry.
[26]Google Cloud 2019.
[27]Google Cloud 2019.
[28]It should be noted that if the *Workbench* does inspire or develop into a new digital teaching program for students of Egyptology, it will not be the first nor only example of one. As such, it would be more beneficial to design the project so as to attract scholars, students, and interested laypeople, and sufficiently contextualising it in academia.

hieroglyphic data', as well as allow educators to integrate digital technology into their teaching and encourage collaboration, highlight the main interests I have developed throughout this project:

1. Exploring digital tools that can help with the analysis of Hieroglyphic Egyptian
2. Exploring digital tools that can help with the teaching of Hieroglyphic Egyptian
3. Exploring digital tools that can help with collaboration among Egyptologists worldwide

While my case study focused on (1), I came to see potential for the *Fabricius Workbench* to either provide a framework – or at least inspiration – for future projects that explore potential digital tools that can be integrated into teaching Hieroglyphic Egyptian and create an environment of collaboration on a broader scale.

1.2 Case Study

The case study undertaken during this project aimed to investigate the idea put forward by Robert Licklider that 'man-computer symbiosis' allows 'intellectual operations' to be performed far 'more effectively than man alone can perform them.[29] Eight volunteer Egyptologists were asked to complete one manual translation of an ancient Egyptian text, and one translation using the *Fabricius Workbench*. Participants were interviewed both before completing either translation, as well as after having completed both translations. They were asked to provide feedback on their experience using the program, how it compared to manual translation, and how they visualised an improved version of the program. Each participant was shown the tutorial I created for Google Arts and Culture before engaging with the *Workbench*, and was observed throughout each translation session, with any remarks, mistakes, or technical issues being noted.[30]

[29] Licklider 1960, 4.

[30] View the tutorial I created for Google Arts and Culture here: **Explore the Fabricius Workbench** (Kelly, Ballsun-Stanton and Woods 2020b); I also produced two other Google Arts and Culture

1.3 Research Outcomes

In order to address the research questions outlined in § 1.1, the contexts surrounding machine learning, digital research tools, and the translation of ancient Egyptian hieroglyphic texts are addressed in the literature review (see Chapter 2). This involved delving into the history of Egyptian epigraphy and how it has evolved over the years, what digital tools have been adopted by the Egyptological community more generally, and the challenges that digital technologies introduce. Following this, I was able to develop a theoretical (§ 3.1) and analytical framework (§ 3.2) for the case study, as well as establish the case study structure (§3.3), including choosing the texts to be translated (§ 3.3.5), formulating interview questions (§ 3.3.7 and § 3.3.10) and planning the observation sessions (§3.3.6). Using the feedback of the observation sessions and interviews, in addition to collecting data on the program's ability to identify hieroglyphs, I was able to determine the accuracy, utility, and usability of the program. By employing a SWOT approach to the results, I identified the strengths, weaknesses, opportunities, and threats of the project with a focus on user experience (§ 3.2.1 and § 5.3). This approach to the concept of humans and machines working in partnership employs the theoretical considerations of *diffusion of innovation theory* (§ 3.1.2) and *design thinking* (§ 3.1.3). The outcomes of the case study are then summarised in Chapter 4 and discussed in Chapter 5. Specifically, the discussion in Chapter 5 considers the following:

1. Results on the accuracy of the *Auto classify* function in the *Fabricius Workbench*

2. Feedback on user experience of case study participants using the *Fabricius Workbench*

3. Discussion on potential improvements to components of the *Fabricius Workbench*

4. Discussion on what can be learned about digital tools applied to research

Stories alongside the tutorial: one exploring the history of Egyptian epigraphy (see **Decoding Ancient Egyptian Hieroglyphs** (Kelly, Ballsun-Stanton and Woods 2020a)), and the other demonstrating ways in which Macquarie University's Ancient History department has embraced digital technologies into Egyptological research (see **Egyptology and Technology** (Kelly, Evans and Ballsun-Stanton 2020)).

5. Discussion on potential of using the *Fabricius Workbench* as the framework for a teaching tool

After completing the case study, I believe the *Fabricius Workbench* could be suited to forming the framework of a teaching and training program for students learning Hieroglyphic Egyptian. It could be designed to offer activities and exercises that help students become familiar with the encoding and marking up of hieroglyphs. That is not to say, however, that the *Workbench* cannot still inform the development of future digital tools for career researchers. With more robust training sets, the hieroglyph classification aspect of the *Workbench* could greatly improve its accuracy and thus provide some future benefit to Egyptologists conducting epigraphic and philological research on hieroglyphic texts. The *Fabricius Workbench* may have been released pre-maturely, but it does represent a basis upon which future digital tool sets for Egyptologists can be developed.

Chapter 2

Literature Review

Although the adoption of digital technologies into Egyptological research has not always been smooth, computers have had an undeniable impact on Egyptology and the ways Egyptological research is conducted: tracing paper has evolved into the digital drawing tablet, manual typesetting can be improved with hieroglyphic fonts, and text corpora can be stored digitally.[31] Egyptian epigraphy has adopted new techniques and tools for producing precise records of ancient Egyptian inscriptions, which is a 'scholarly necessity' as they are our primary source for language and text in ancient Egypt.[32] This chapter provides a brief outline of the history of Egyptian epigraphy, hieroglyphic encoding, including the Unicode system and fonts, digital text and hieroglyph corpora, the *Manuel de Codage*, the issue of link rot, and the reception of digital technologies into Egyptology over the years. This will establish the environment in which the *Fabricius Workbench* has been developed.

2.1 James Henry Breasted and The Epigraphic Survey

Jeffry Abt defines Egyptian epigraphy as the 'documentation of ancient hieroglyphs and pictorial reliefs'.[33] Early examples of Egyptian epigraphy include the drawings of the French savants who journeyed with Napoleon Bonaparte into Egypt in the

[31] Der Manuelian 1998, 101–102.
[32] Abt 1998, 20.
[33] Abt 1998, 19.

1790s.[34] In the following decades, scholars such as Jean-François Champollion and Karl Richard Lepsius, led equally productive expeditions into Egypt.[35] It was within the framework established by his European predecessors that James Henry Breasted developed the Chicago House Method.[36]

Abt investigates the Chicago House Method, as well as the 'context of the patronage system cultivated to support it', which highlights one of the most important aspects of innovation within research – securing funding.[37] In order to move forward with his new method of capturing inscriptions, by developing large-format photographs on-site and adding details in red ink, Breasted needed to appease the wealthy philanthropists and investors who were captivated by the idea of 'scientific' study.[38] With Breasted's establishment of the Oriental Institute of the University of Chicago (1919), 'ongoing research programs' such as the Epigraphic Survey (1924) were set up.[39]

By the time Breasted established the Oriental Institute, the practice of reading and translating Egyptian hieroglyphs was already well-established, and a new, more rigorous approach to Egyptian grammar and lexicography was being developed under the leadership of Adolf Erman.[40] Erman was Breasted's mentor and the founder of the Berlin Dictionary project, designed to enable 'scientific and accurate translations' of Egyptian texts.[41] As a result of Erman's training and influence, Breasted recognised the importance of recording inscriptions with the utmost accuracy in order to 'facilitate correct translation and analysis'.[42] As the most precise and accurate translations are those produced through direct consultation of the source inscription, the introduction of photography as a vital component of the epigraphic process employed by the Epigraphic Survey was a key development in the history of Egyptian epigraphy.[43] Photography was, however, less affordable during Breasted's career than today, and object-finding

[34] Abt 1998, 21; L. Adkins and R. Adkins 2001, 242.
[35] Abt 1998, 21; L. Adkins and R. Adkins 2001, 176; It is important to acknowledge that although Western scholars such as Champollion and Lepsius are typically better known for their contributions to the decipherment of hieroglyphs, there was a distinct Arab interest in the subject during the Medieval Period (El Daly 2005).
[36] Abt 1998, 270-323.
[37] Abt 1998, 19; Gozzoli 2013, 95.
[38] Abt 1998, 19, 26-31.
[39] Abt 1998, 19-20.
[40] Abt 1998, 22.
[41] Abt 1998, 22; Bierbrier 2019, 152.
[42] Abt 1998, 22.
[43] Der Manuelian 1998, 100; Nederhof 2013b, 104.

archaeological projects attracted funding more easily than those concerned with text.[44]

Breasted consolidated the Epigraphic Survey's rigorous epigraphic method by advertising the philological approach to Egyptian texts as a scientific endeavour that required meticulous recording through direct consultation of the monuments.[45] The Epigraphic Survey carries out its work in Egypt to this day and has embraced digital tools and technologies as means of enhancing the epigraphic process.[46] By collaborating with experts in digital approaches, they have positioned themselves as a leading force in digital epigraphy in Egyptology and thereby provide a prime example of how digital tools can be utilised in research to complement the long-standing traditions of Egyptology whilst maintaining an extremely high standard of accuracy (§ 2.2.3).

2.2 Digital Tools in Egyptology

As exemplified by the Epigraphic Survey, Egyptologists have adopted various forms of digital technologies into their research and teaching practices.[47] This includes digital databases of textual, visual, and archaeological material, text fonts, typesetting programs, digital drawing programs, digital drawing tablets, and photographic devices.[48] In addition to the Epigraphic Survey, significant names that have engaged in the conversation about digital technologies in Egyptology include Mark-Jan Nederhof, Sétphane Polis, and Serge Rosmorduc. They have been consistently involved in proposals for hieroglyphic Unicode code points, the development of text and hieroglyph databases, and Rosmorduc was instrumental in the Ramses Project (as was Polis) and the creation of *JSesh* (§ 2.2.1).[49]

[44] Abt 1998, 20.
[45] Abt 1998, 19-20.
[46] To view work being undertaken by The Epigraphic Survey, see: **The Epigraphic Survey | Research Projects** (The Oriential Institute of The Univeristy of Chicago 2021) and **digitalEPIGRAPHY | About Us** (Vértes 2021)
[47] Mansour and Ezzat 2015, 362; Nederhof 2013a, 85-86.
[48] Der Manuelian 1988; Gozzoli 2013; Rosmorduc, Polis and Winand 2009.
[49] Gozzoli 2013, 93; Université de Liège 2021; Polis, Honnay and Winand 2013; Nederhof 2016; Nederhof, Rajan, Lang *et al.* 2016a; Nederhof, Rajan, Lang *et al.* 2016b; Nederhof and Rajan 2016; Nederhof, Polis and Rosmorduc 2021; Rosmorduc 2014; Rosmorduc 2017; Notable figures in this discussion include Deborah W. Anderson (who wrote about the **Script Encoding Initiative at UC Berkeley** in 2015) and Donald Mastronarde (who created Unicode fonts and transliteration keyboards for **Demotic Egyptian**), as well as the Berlin branch of the Thesaurus Linguae Aegyptiae (BBAW - Ancient Egyptian Dictionary Project 2021), particularly Ingelore Hafemann

Since digital technologies facilitate communication and information transfer, they have become an essential aspect of modern collaborative research. 'Computer-aided' research has become more commonplace in Egyptology with the inclusion of hieroglyphic characters in Unicode, hieroglyphic text processors and digital epigraphy.[50] § 2.2.1 – § 2.2.3 explore the development of the digital tools adopted and created by Egyptologists, starting with the Unicode system of character code points for hieroglyphs, hieroglyphic fonts and text editors, then discussing digital databases and corpora, and finally, digital epigraphy.

2.2.1 Encoding Hieroglyphs: Unicode, Fonts, and Text Editors

Unicode is a character encoding standard for which support is available by most modern programming languages and operating systems.[51] It provides a means of encoding characters digitally so that they can be read by a computer and transferred between programs without losing data or readability. Fonts are used to represent Unicode characters in text editing programs like *Microsoft Word*. Using fonts that rely on character substitution rather than Unicode can therefore be problematic. For instance, when using a character substitution font to print the Egyptian transliteration character š, the user inputs the ASCII character S and the font presents this to the user as š.[52]

Instead, Unicode encodes the Egyptian transliteration character š as Unicode code point U+0161, which increases its readability and allows any computer to interact with an unambiguously encoded character.[53] This is important, as

and Simon Schweitzer; Bob Richmond, Andrew Glass, and Michael Everson have also been quite involved in the push to get hieroglyphic characters included in the Unicode format (Gozzoli 2013, 92): see, for example, Richmond 2015; Richmond and Glass 2016; Everson 2006; Everson and Richmond 2008.

[50] The discussion around the development of Unicode character points for Hieroglyphic Egyptian slowed around 2010, but was revived in the **DHEgypt15** Conference, hosted by Monica Berti and Franziska Naether in 2015 (Berti and Naether 2015; Jushaninowa 2015). Earlier this year, Nederhof, Polis, and Rosmorduc produced a document on updated control characters for Hieroglyphic Egyptian in Unicode, developing on their previous proposals from 2016 (Rosmorduc 2021).

[51] Bigelow and Holmes 1993, 289–290; Nederhof, Polis and Rosmorduc 2021, 2.

[52] 'ASCII stands for American Standard Code for Information Interchange. Computers can only understand numbers, so an ASCII code is the numerical representation of a character' (ASCII 2021)

[53] A total of 1071 code points of Egyptian hieroglyphic signs were introduced into Unicode by version 5.2 in 2009 (Nederhof 2013b, 103–4; Nederhof, Polis and Rosmorduc 2021, 4); These code points can be found in version 13.0 here: **Egyptian Hieroglyphs | Range: 13000 – 1342F**; It should be noted that whilst a large portion of both hieroglyphs and the characters used in the transliteration of Hieroglyphic Egyptian are included in the Unicode standard, there are still examples of severe shortcomings, like the Egyptological yod (U+A7BD/U+A7BC), which, whilst it has been added to the Unicode standard, is still not supported by most fonts (see **Unicode Charater | U+A7BD**;

machine readability is a necessary prerequisite for publishing FAIR (Findable, Accessible, Interoperable, and Reproducible) data.[54] It also enables digital analysis of encoded hieroglyphic data and ensures that data experiences as little data loss as possible.[55] Data loss is common when using character substitution fonts, which are often tied to the program that created them and can be lost when transferred from that environment. As a result, meaningful data exchange is not possible using such fonts, which highlights how crucial it is to establish a universal standard of encoding like Unicode as Egyptological research and teaching moves towards a digital format.

Hieroglyphic character substitution fonts and text processors have been used since the 1960s, including *Glyph*, *CorelDraw*, *MacScribe*, *WinGlyph*, *Inscribe*, *VisualGlyph*, *JSesh*, *VectorOffice*, and *ProGlyph*.[56] They were developed to be compatible with either Windows or Apple computers, or sometimes both.[57] For example, the hieroglyphic font *ProGlyph*, created by Michael Berger of the aforementioned Oriental Institute, was designed to work on Apple Macintosh computers only.[58] Whilst not the only font and text editor available for the Macintosh computer – *MacSribe* and *MacHieroglyphs* are two other examples – Peter Der Manuelian argues that *ProGlyph* was the most versatile for the time.[59] He points out that although transcribing a long sentence in hieroglyphs using a font such as *ProGlyph* could be tedious, being able to correct a mistake or add an hieroglyphic sign by 'merely "sliding" hieroglyphs across the screen to make room for additional signs' is far easier than having to completely re-write an entire sentence when using ink and paper.[60] Der Manuelian argues that *ProGlyph* provided consistency and editability which allowed Egyptologists not specially trained in the use of computers to engage with digital type-setting for hieroglyphs.[61] He concludes his article by identifying the potential for such digital innovations to enable greater storage of 'computer-composed inscriptions', using databases for both hieroglyphs and general information; additionally, he argues, with the 'barriers' between the

Unicode Charater | U+A7B; Rosmorduc 2020b.
[54] ANDS 2021.
[55] Nederhof, Polis and Rosmorduc 2021, 2–3.
[56] Der Manuelian 1988; Gozzoli 2013, 89, 90, 93, 94; Strudwick 1988.
[57] Gozzoli 2013, 90.
[58] Der Manuelian 1988, 237; Strudwick 1988, 7.
[59] Der Manuelian 1988, 237, 238; Gozzoli 2013, 90.
[60] Der Manuelian 1988, 238.
[61] Der Manuelian 1988, 240.

various types of hieroglyphic programs beginning to ‘diminish’, ever more intuitive ways of integrating computers into Egyptological research are made possible.[62]

A rise in the use of computers in Egyptological research in the late 1980s enabled the transition from handwritten to digitally typeset hieroglyphs.[63] The *Manuel de Codage*, published in 1988, advanced this trend.[64] These text processing programs were supported by the *Manuel de Codage* as well as tools such as *Hieroglyphica*, which was a ‘library of Late Period and Ptolemaic signs’, first released in the late 1990’s.[65]

2.2.1.1 ***The Manuel de Codage***

The *Manuel de Codage* (MdC) established conventions for formatting encoded hieroglyphs, manipulating the appearance and placement of signs.[66] Although it was a monumental development for computer-aided research of texts and language, it was not without its faults.[67] Introducing a complex system like hieroglyphic script into the world of binary and Unicode leads to a number of ambiguities. For example, Egyptologists have a certain understanding of what is meant by ‘character’ and ‘glyph’ when discussing the language system of ancient Egyptian hieroglyphs. However, when it comes to Unicode, ‘character’ refers to the ‘smallest component of written language’, and ‘glyph’ refers to the rendered shape of a character.[68] As a result, Egyptologists tend to want to encode the ‘glyphs rather than the characters’; Nederhof demonstrates this confusion using the two ‘glyphs’ that both represent the same ‘character’: 𓅱 (G43) and 𓏲 (Z7), which both represent ‘w’.[69]

Although the MdC formed the basis for hieroglyphic typesetting for many years, Nederhof released some criticisms against the system with a view of introducing the Revised Encoding Scheme (RES) in 2002.[70] The RES proposed a much more flexible algorithm for the ‘scaling and positioning’ of hieroglyphic

[62] Der Manuelian 1988, 240.
[63] Gozzoli 2013, 89.
[64] Gozzoli 2013, 89; Nederhof 2013b, 106.
[65] Gozzoli 2013, 90.
[66] Nederhof 2002, 1–8.
[67] Gozzoli 2013, 89, 96.
[68] Nederhof 2013b, 104.
[69] Nederhof 2013b, 104.
[70] Nederhof 2002.

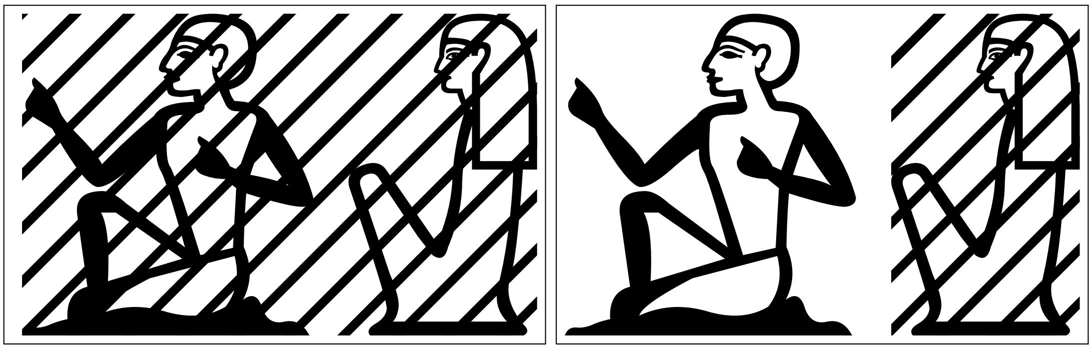

Figure 2.1: *JSesh* rendering of (A1B1)# (left) and A1(B1#) (right).

signs that is font-independent, allowing it to be applied much more broadly.[71] The same concept of universality is applied to the RES's use of primarily Roman letters for operators and functions, limiting special symbols, and correcting the issues of precedence inherent in the MdC's 'bizarre syntax. For example, operator precedence is counter-intuitive. Most notably, # is often mistakenly assumed to have a higher precedence than * and :. E.g. A1*B1# means (A1*B1)# rather than A1*(B1#)'.[72] This results in an incorrect representation of what the user is trying to achieve (Fig. 2.1).[73]

Another of Nederhof's criticisms concerned the limited options for encoding the position of hieroglyphs in relation to each other.[74] Nederhof describes the MdC as 'inadequate' and notes that advancements made to hieroglyphic text editors are not always well documented.[75] He also highlights that the MdC was not even originally intended to be a standalone system for encoding, but was linked to a specific tool (*Glyph*, mentioned above).[76] This contradicts the ideal characteristics of computer software that demonstrate 'longevity and versatility'.[77]

2.2.2 Digital Databases and Corpora for Hieroglyphic Signs and Texts

In addition to the fonts and text processors developed over the years, there are also a number of textual and hieroglyphic sign databases and corpora. However,

[71] Nederhof 2002, 3, 4.
[72] Nederhof 2002, 6.
[73] Where Der Manuelian argues for non-specialist researchers to be able to use hieroglyphic programs, Nederhof expresses that it is also ideal for non-specialist software to be required, thus making the process more accessible (Der Manuelian 1988, 240; Nederhof 2002, 11).
[74] Nederhof 2002, 2–6.
[75] Nederhof 2013b, 106.
[76] Nederhof 2013b, 106.
[77] Nederhof 2013b, 105.

not all of them have survived.[78] Carlos Gracia Zamacona claims that computers are a necessity when dealing with large corpora of material.[79] Such databases inevitably involve database tools, including *SESCH*, *Corpus*, and *TkSesh*, which is an hieroglyphic database system developed in the 1990s.[80]

Ramses is a database that was first presented in 2008, championed as an 'interdisciplinary project' with the ambitious aim of 'building…an annotated corpus of all Late Egyptian texts'.[81] The project was intended to be compatible with both Windows and Macintosh computers, and the chosen format complied with the recommendations of the *Text Encoding Initiative* (TEI), which provides guidelines for how digital text data are created and managed within the humanities.[82] The database is kept up to date, with new information added whenever 'new words, new spellings or new analysis appear'.[83] In the spirit of accuracy and minimising biases, the database also has a 'dedicated routine' for dealing with ambiguities that arise, 'whether lexical, morphological or syntactical'; all possible analyses are encoded, allowing for the user to reach an informed conclusion.[84] A database such as *Ramses* provides researchers and students of the ancient Egyptian hieroglyphic language with a searchable repository of information that can assist in translating texts.[85] Another online corpus is the *Thesaurus Linguae Aegyptiae* (*TLA*), which contains texts from various time periods of ancient Egyptian history and includes multiple well-known collections, such as the *Pyramid Texts* and the *Book of the Dead*.[86] Using this bank of texts, users can search for words, word phrases, or texts using a bibliographic reference, transliteration, English, or even using Gardiner Codes.[87] Such projects employ frameworks, such as the MdC and RES, in order

[78] Gozzoli 2013, 99.

[79] Gracia Zamacona 2013, 139.

[80] Gozzoli 2013, 93, n. 16, 97–98; It is beyond the scope of this thesis to discuss database tools further, but for more information on *SESCH* see **SESCH | Willkommen zur Ägyptologischen Datenbank AHA, Berlin** Holzhäuer 2021; To learn more about *TkSesh*, see **TKSESH | A hieroglyphic database system** Rosmorduc 2021

[81] Polis, Honnay and Winand 2013, 25; Rosmorduc, Polis and Winand 2009, 133.

[82] Rosmorduc, Polis and Winand 2009, 133; For information on the TEI see **TEI | Text Encoding Initiative** (TEI 2021); The TEI establishes a number of focal characteristics aimed at maintaining versatility and reproducibility – 'meaning before format', 'software independence' and being 'community driven' (Burnard 2014, 7–11)

[83] Rosmorduc, Polis and Winand 2009, 136.

[84] Rosmorduc, Polis and Winand 2009, 137.

[85] To view the search function of *Ramses*, see **Ramses Online | an annotated corpus of Late Egyptian** (Université de Liège 2021).

[86] See **Thesaurus Linguae Aegyptiae** (BBAW - Ancient Egyptian Dictionary Project 2021).

[87] Gardiner's 'Sign List' was first published in his book *Egyptian Grammar: Being an Introduction to the Study of Hieroglyphs*: (Gardiner 1927); a second and third edition of this book were published in 1950 and 1957, respectively. Gardiner 1957 contains the *Sign List* and its *Index* on pages 438–548.

to shape their development and maintain consistency among digital Egyptological endeavours.[88]

2.2.3 Digital Epigraphy

Digital epigraphy has been described as 'a boon to archaeological practice in Egyptology'.[89] Computerised methods of epigraphic recording began in the 1990s, completely revolutionising the process.[90] Previously, epigraphers had to rely on making 1:1 tracings on site, which can affect the preservation of the inscriptions being copied. Building on the pioneering efforts of previous Egyptologists, such as Breasted, epigraphy has evolved over time to involve many different techniques and methods.[91] These methods aim to produce the most accurate reproductions possible whilst also preserving the monuments as much as possible. Digital epigraphy not only helps preserve the ancient sites themselves, but it also expands the possibilities available to researchers that traditional methods do not offer.[92]

Der Manuelian states that the need for Egyptian epigraphy to adopt 'new technologies' stemmed from both the need to conserve and protect ancient monuments and the potential for streamlining the process – essentially re-designing the 'traditional documentation methods'.[93] He points out that although facsimiles are an 'indispensable part of proper documentation', their creation often invites 'bias or oversight' from the artist.[94] Another aspect of producing facsimiles is the nature of human eyesight, which deteriorates with age and varies from person to person.[95] Digital tools can, however, help mitigate this.

Der Manuelian emphasises that the 'best examples of Egyptological epigraphy' are produced when different talents are contributed to the process (i.e. when 'photographers, artists, epigraphers and Egyptologists' work together).[96] Alberto Urcia, John Darnell, Colleen Darnell, and Sara Zaia agree, stating that

[88] *Transliteration* refers to the system of rendering the phonetic qualities of hieroglyphic signs in alphabetic characters (example: *ḥtp ḏi nsw*).
[89] Evans and Mourad 2018, 78.
[90] Evans and Mourad 2018, 78.
[91] Der Manuelian 1988, 97.
[92] Urcia *et al.* 2018, 170–171.
[93] Der Manuelian 1998, 97.
[94] Der Manuelian 1998, 97.
[95] Evans and Mourad 2018, 78.
[96] Der Manuelian 1988, 97–100; Urcia *et al.* 2018, 175.

'new digital techniques...combine easily available technology with archaeological expertise' to produce facsimiles that follow the conventions of accuracy and precision established early on in Egyptian epigraphy.[97] Following this reasoning, the *Workbench* combines a number of skills, including tracing, drawing, and identifying. It also allows colleagues to easily collaborate, as their progress can be shared as a transferrable file and uploaded to multiple computers.

The website *digitalEPIGRAPHY*, an initiative associated with The Epigraphic Survey and The Oriental Institute, is described by its creator Krisztián Vértes as an 'educational hub' for both researchers and interested non-specialists to learn about the 'digital documentation techniques' employed by current epigraphers in Egyptology.[98] The researchers involved in the projects published on *digitalEPIGRAPHY* are highly skilled and make full use of digital tools, such as high-resolution cameras, photogrammetry, and digital drawing tablets and their associated software.[99] As a result of this approach to modern-day epigraphy, highly accurate and shareable results are being produced and made available via their website.[100]

Another advantage of digital epigraphy is the potential for more efficiency. Sam Mayo of Google ZOO stated in 2019 that the *Workbench* could 'speed up' the process of facsimile creation, which would 'give Egyptologists more time to focus on addressing more interesting and complex problems'.[101] Mayo's words echo Der Manuelian's prediction that 'digital epigraphy' could 'accelerate' the process and 'allow for the documentation of more monuments in less time'.[102] Der Manuelian also identifies the role of the computer in Egyptian epigraphy as not a replacement for human researchers, but rather a tool that can assist

[97]Urcia *et al.* 2018, 169.

[98]See **digitalEPIGRAPHY | About Us** (Vértes 2021).

[99]The Oxford English Dictionary defines photogrammetry as the 'technique of using photographs to ascertain measurements of what is photographed' (Oxford English Dictionary 2020b); Samaan *et al.* write that it is 'a technique used to reconstitute a three-dimensional scene from a series of images taken with an appropriate protocol' and has been in use for over 50 years in surveying, but is now an established practice in archaeology and can be automated up to some extent' (Samaan *et al.* 2016, 1–2).

[100]Another website that offers insights into the work of skilled epigraphers is **Digital Epigraphy** by the University of Florida.

[101]Google Cloud 2019; Google 2021c; *Never Sit Still* describes Google ZOO as 'Google's creative think tank of technologists and artists who work with brands and agencies' and 'help their partners do creative things with Google technology that have never been done before' (Never Sit Still 2020).

[102]Der Manuelian 1998, 98.

in and enhance the epigraphic process.[103] In fact, the relationship between the human mind and computers has been theorised to produce better results than human intellect alone.[104] Following this concept, Egyptologists could potentially develop ever more efficient epigraphic methods that take advantage of automatable processes and by using several different tools to produce the most accurate results possible.

An example of machine learning being applied to the analytical stage of digital epigraphy is the program called *Pythia*.[105] Although this program is concerned with ancient Greek inscriptions rather than Egyptian, and is designed to predict missing characters rather than identify them, it demonstrates that, if utilised correctly, machine learning-driven techniques show great potential for the research of ancient languages. The software is highly intuitive and can predict the missing text of damaged ancient Greek inscriptions at a high rate of accuracy. According to the study, the program had a character-error rate of 30.1%, compared to the 57.3% character-error rate of human epigraphers.[106] These are promising figures that demonstrate the benefit of using computers to improve research practices. As with the *Workbench*, *Pythia* was also released as an open-source program, 'in the hope that it will be of help to future research and inspiration for future interdisciplinary works'.[107]

Although digital epigraphy and other digital approaches to the study of Hieroglyphic Egyptian have shown positive results from digital cameras and drawing tablets, the nature of digital – and especially online – tools is that they can be short-lived. For an online resource or database to survive over time, it must be maintained, which requires time, effort and funding. If these requirements are not met, online sources can become defunct, or outdated.

[103] Der Manuelian 1998, 98.
[104] Licklider (1960) coined the term 'Man-Computer Symbiosis' (Licklider 1960, 4–6); Guszcza, Evans-Greenwood and H. Lewis 2017, 10–12.
[105] Assael, Sommerschield and Prag 2019.
[106] Assael, Sommerschield and Prag 2019, 6371.
[107] Mantovan and Nanni 2020, 26; Some examples of digital tools built for Hieroglyphic Egyptian include Rosmorduc's 'Deep Learning experiment' with the automated transliteration of Late Egyptian (Rosmorduc 2020a), a study by Stéphanie Gohy, Benjamin Martin Leon and Stéphane Poilis that explored implementing Automated Text Categorisation to build 'automatic text classifiers' for digitised Late Egyptian texts (Gohy, Martin Leon and Polis 2013), and an attempt by So Miyagawa and Marwan Kilani, in collaboration with David Chapman and Camilla Di Biase-Dyson of Macquarie University to use Google Japanese Input Dictionary Tool to type hieroglyphs using the keyboard (Kilani *et al.* 2021; Migawa 2020).

2.3 The Issue of Link Rot

A common issue for online resources is *link rot*, where a website becomes inactive over time, or the domain changes owner, and thus the original link becomes inaccessible.[108] Link rot was identified over 20 years ago, with suggestions such as running 'link validators...at regular intervals', 're-architect a site and impose a new structure', and 'set up a set of redirects'.[109] Despite its notoriety, the problem does not appear to be widely nor consistently addressed in digital scholarship, much less within the adoption of digital technology in Egyptology.[110] Due to the growing trend to cite online resources in research, link rot is an ever-present threat to the longevity of information.[111] For example, it transpired that when looking for more information on the 'CCER' mentioned several times in Gozzoli's paper, I found that the link provided loaded a site for the *Center for Computational Energy Research*, not the *Centre for Computer-aided Egyptological Research*, as expected.[112] I found the archive entry for the *Centre for Computer-aided Egyptological Research* on the *Electronic Tools and Ancient East Archives* (ETANA) website, however, the outdated link was recorded there as well.[113] Access to previous versions of the site via **archive.org** revealed that the URL provided belonged to the *Centre for Computer-aided Egyptological Research* only until August of 2009. By April 2011 the site was listed as closed and by October 2017 it was attributed to the *Center for Computational Energy Research.*

It is evident that whilst there are sometimes ways of retrieving websites affected by link rot, it is far more important and effective to prevent the issue from occurring in the first place, by using services designed to ensure the survival of links, such as **PermaCC** or **archive.org**.[114] It is possible that due to the

[108] Król and Zdonek 2019, 20.

[109] Nielson 1998.

[110] Gozzoli 2013, 98; Król and Zdonek 2019, 21; It is important to be aware throughout this project of the phenomenon known as 'bit rot', which involves 'software erosion' and 'hardware erosion', eventually resulting in slower or even obsolete software (Król and Zdonek 2019, 21–23) – consider, for example, Peter Jurgen's *Access* database for Coffin Texts, which was created in a format later made obsolete, with the database itself being removed from public access (Gozzoli 2013, 99).

[111] Król and Zdonek 2019, 21; Król and Król and Zdonek provide an incredibly informative overview of the link rot and bit rot phenomena and include an extensive bibliography of works regarding both link rot and ways of preventing it (pp. 33-37).

[112] Gozzoli 2013 provides the link: https://www.ccer.nl/ on page 100, which loads the *Center for Computational Energy Research*'s website – it should be noted that Gozzoli does acknowledge that the CCER shut down (p. 91), but still provides the un-archived web link.

[113] See **Centre for computer-aided Egyptological Research (CCER) | ETANA**.

[114] All of the links provided in this thesis have been archived via **archive.org** using a script, but some

complex and often unfamiliar issues that arise, such as link rot, some Egyptologists hesitate to accept the use of digital technologies in their research.

2.4 Adoption of Digital Technologies into Egyptology: Attitudes and Reception

Der Manuelian wrote in 1988 of the range of attitudes towards the adoption of 'modern methods in the study of ancient cultures', from approval to rejection, with a view that these 'modern methods' – particularly hieroglyphic text-processors – are 'cold, un-aesthetic creatures'.[115] There was even a time some epigraphers 'shunned' the idea of tracing over photographs.[116] However, notable examples of innovation and adoption of technologies among Egyptologists bear mentioning, as discussed in digital-tools-in-egyptology. Technological innovations have had an undeniable impact on the way in which research is carried out in Egyptology.[117] The computer has even become a 'vital part of the...process' for some epigraphic projects, such as the '*Giza Mastabas* series'.[118] Yale Egyptology began 'actively' incorporating technology into their research on rock art and inscriptions from 2010.[119] Nigel Strudwick praised *ProGlyph* when it was released in the 1980s and encouraged Egyptologists who utilised computers in their research to consider using the Macintosh.[120]

Expanding further and exploring the more theoretical implications of computer-aided research in archaeology, Robert Chenhall identifies the ability of computers to process large amounts of data quickly, and without 'getting tired'.[121] Computers offer objectivity (in certain applications), reproducible data formats, and data processing – 'exciting possibilities for the future of archaeological research'.[122] Chenhall was writing in 1968, and it was through an optimistic and ambitious outlook like his that the technological advances that have developed since then

did not archive cleanly and therefore are presented with their original url.

[115]Der Manuelian 1988, 237.
[116]Caminos and Fischer 1976, 11.
[117]Der Manuelian 1988, 237.
[118]Der Manuelian 1998, 100.
[119]Urcia *et al.* 2018, 170.
[120]Strudwick 1988, 9.
[121]Chenhall 1968; Guszcza, Evans-Greenwood and H. Lewis 2017, 13.
[122]Chenhall 1968, 21.

took place. It is evident that Egyptologists such as Strudwick and Peter Der Manuelian very much embraced using digital tools, with their use of hieroglyphic fonts in the 1980s, as well as Serge Rosmorduc.[123] It is hoped that the results of the case study of this thesis demonstrate that Egyptologists can effectively work with digital tools to continue improving epigraphic methods, and language studies, as well as research and teaching practices in general.

2.5 Conclusion

There are numerous benefits to integrating digital approaches into the practice of Egyptian epigraphy. The multitude of tools available to researchers encourages collaboration and consistency in documentation. Digital epigraphy has been observed to streamline the process of recording inscriptions, as well as prevent further damage to the rapidly deteriorating monuments of ancient Egypt. Digital tools allow for easy communication, and give researchers the ability to store, share, and analyse large amounts of data. The *Workbench* has the capacity for all three, and although the program has limitations, it has the potential to evolve a more viable collection of tools for the capture and analysis of Egyptian hieroglyphic texts. When working with such technologies, one must be conscious of the risks, such as link rot, but with the appropriate knowledge and systems in place, these can be anticipated. The case study undertaken in this project investigated the precise ways in which the *Fabricius Workbench* can inform future digital tools for Egyptologists focusing on epigraphy and language.

[123] Gozzoli 2013, 90; Rosmorduc 2014.

Chapter 3

Methodology

In order to evaluate how digital tools might be integrated into epigraphic and/or language research in Egyptology, a theoretical and analytical framework must be established. The nature of the *Fabricius Workbench* project, being a product as well as a proof-of-concept, requires exploring *diffusion of innovation theory*, and *design thinking* is employed to consider the nature of designing and developing such projects.

The case study described below (§ 3.3) sought to answer the research questions 1–4 outlined in § 1.1, while question 5 is discussed in Chapter 5. This chapter outlines how eight volunteer Egyptologists tested the *Fabricius Workbench* in its current state after which I evaluated its effectiveness as a digital tool for translating ancient Egyptian hieroglyphic texts. From this, § 5.4.1 explores the manner and extent to which each element of the *Workbench* could be adapted or expanded upon.

3.1 Theoretical Framework

A combination of the following theoretical frameworks are applied to investigate what can be learned from the *Fabricius Workbench*: *diffusion of innovation theory*, which investigates the process of technology adoption and *design thinking*, which is a methodological approach to improving a product.

3.1.1 Diffusion of Innovation Theory

Diffusion of innovation theory describes the process by which innovations are adopted into use. It starts with the innovators, who are driving the change and taking risks, then the early adopters, followed by the early, then late majority, who are slower to adopt and seem to be influenced by what other people are doing, then the laggards, who are the last to accept the change.[124] This curve has been refined by the identification of a 'chasm', the particular gap between the early adopters and the early majority, which can be difficult to cross.[125]

Although the *Fabricius Workbench* as it stands currently is not a useful product for Egyptologists, it can form the basis of future products that could 'cross the chasm' at some point. Many innovations and the companies behind them fail despite the best efforts of those involved.[126] To avoid this fate, the product must evolve, address the weaknesses of early versions and speak to the needs of the intended audience: Egyptologists. Companies like Google and Psycle can be innovators, as can Egyptologists trained in information technology, like Rosmorduc and Nederhof, but the wider Egyptological community are more likely to form the late majority (see § 2.4).[127] In order to cross this chasm, these products must appeal to both career research and educators. Introducing such tools into the delivery of Egyptological teaching material would help educators experiencing the COVID-pivot migrate further towards a digital means of educating and encourage students to incorporate such human-computer methods and skills into their later careers.[128]

3.1.2 Design Thinking

Diffusion of innovation considers how digital innovations are distributed to the market, and design thinking responds to this challenge by determining the 'what' and 'how' required to attain an aspired value (Fig. 3.1).[129] Ubisoft appeared to approach their project with a focus to demonstrate how machine learning can be

[124]Kaminski 2011, 3; Rogers 2003, 191.
[125]Moore 2014.
[126]Ries 2011, 1–4.
[127]This is discussed further in § 5.3.4.
[128]Anderson 2020.
[129]Dorst 2011, 522-523.

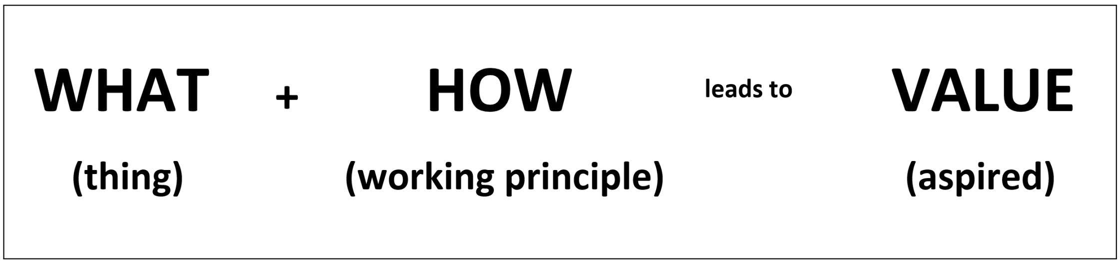

Figure 3.1: Knowing the 'what' and 'how' of a design can be useful for ascertaining an aspired value (Dorst 2011, 523).

beneficial to the translation of ancient Egyptian hieroglyphic texts, using machine learning, which would lead to an undefined end result. This result took the form of the *Fabricius Workbench*. The process of design thinking could be applied to future improvements of aspects of the *Workbench* to produce more applicable digital tools for the Egyptological community.

3.2 Analytical Framework

During the observation sessions of the case study, I identified common themes that can be observed among the interview answers across the users and evaluate this information to determine what aspects of the program might best integrate into the Egyptological research. It is important to clarify the difference between usability and user experience, as evaluation of usability can indicate how suitable a tool is for specific tasks, whilst user experience allows for more insight into the thoughts and perceptions of the users participating in the case study.[130] I looked for feedback from testers that indicated in what ways digital tools such as the *Workbench* could assist in the translation process (such as combining several resources into one) or other aspects of linguistic study and evaluated the overall user experience to determine what avenues of digital technology might be explored with further research.

3.2.1 SWOT Analysis

A framework for evaluation that has proved useful in past research is SWOT (Strengths, Weaknesses, Opportunities, Threats). Although this method is primar-

[130] Bevan 2009, 2763.

ily employed for evaluation of management and business models, it can be adapted to research, as demonstrated in Marilyn Helms and Judy Nixon's 2010 analysis of the use of SWOT across varying academic research papers.[131] SWOT considers internal and external factors that form a 'strategic matrix'.[132] Internal factors (strengths and weaknesses) include aspects within the control of the organisation and external factors (opportunities and threats) are out of the control of the organisation. When applied to the case study at hand, the internal factors to be identified and analysed relate to the *Workbench* itself, while the external factors relate to funding and challenges facing future developments born out of this project. Although I have limited control over the presentation and operation of the *Workbench* itself, I am able to communicate potential improvements to the development team at Psycle. As such, this SWOT evaluation can effectively be conducted from the perspective of the discipline expert and user, as well as the companies who created the program (Psycle and Google) and any tensions between the two can be considered.[133]

3.3 Case Study Overview and Context

To evaluate how effectively the program works, eight volunteer participants were asked to engage with the *Fabricius Workbench* in conjunction with traditional translation methods (referring to printed grammars and dictionaries) to translate two different passages of hieroglyphic text. Four of the participants were required to first complete the translation task using their preferred manual process, followed by the same activity completed with the assistance of the *Workbench.* The other four participants were asked to complete these activities in the reverse order.

3.3.1 Object of the Case Study: The *Fabricius Workbench*

The gaming company Ubisoft conceived the *Fabricius Workbench* project in 2017 following the development of their video game *Assassin's Creed: Origins*, released that same year. *Assassin's Creed: Origins* was the tenth instalment of their

[131] Helms and Nixon 2010.
[132] Ghazinoory, Abdi and Azedegan-Mehr 2011, 25.
[133] Weihrich 1982, 54.

Assassin's Creed video games series and was set in Ptolemaic Egypt (332 BCE–30 CE).[134] It included a free-to-play mode called *The Discovery Tour*, which allowed players to explore the ancient Egyptian landscape in a virtual capacity whilst learning about the structures, culture, religion, and daily life of the ancient Egyptians. Through the development of both *Origins* itself and *The Discovery Tour*, the Ubisoft team came to see themselves as potentially playing an important role in Egyptological research.[135]

As a result of their collaboration with Egyptological consultant Perrine Poiron, and Google, who supported Ubisoft's marketing of *Origins* in 2017, Ubisoft began developing a research project that aimed to investigate how machine learning might be introduced into the translation of Hieroglyphic Egyptian. Through their collaboration with Google, Ubisoft was able to access the *Google Cloud Platform* and *Auto ML Vision*, which power the machine learning functions of the program. During the years since its conception, the project has developed into the early stage of a larger endeavour proposed by Google.[136] It was released as an open-source browser-based program by Google Arts and Culture (GAC) in July of 2020, and the GAC team hope to use the first version - focused on Hieroglyphic Egyptian - as a framework for developing translation tools for other ancient languages.[137]

Fabricius contains three different modes: *Learn*, *Play*, and *Work*.[138] The *Learn* mode guides users through a short lesson on how to identify a few select hieroglyphs and how they are interpreted, while the *Play* mode allows users to generate phrases and sentences that appear to be 'sent' as a mock social media post.[139] *Learn* and *Play* were developed late in the timeline, and primarily aimed at promoting interest in the program as a whole. The third mode, *Work* (otherwise the *Fabricius Workbench* or the *Workbench*), is the focus of the present case study. The *Workbench* was designed to assist Egyptologists in the process of translating ancient Egyptian texts – specifically Middle Egyptian – and combines the practices of epigraphy (creating drawn copies of texts) and translation into

[134] Google Cloud 2019; Hölbl 2001, 76.
[135] Google Cloud 2018, 1:26:12–1:26:41.
[136] Google Arts and Culture 2020a; Personal communication with Lama El Desouky, Preservation Coordinator at Google Arts and Culture.
[137] Google Arts and Culture 2020a; Personal communication with Lama El Desouky, Preservation coordinator at Google Arts and Culture.
[138] Google Arts and Culture 2020c.
[139] Google Arts and Culture 2020b.

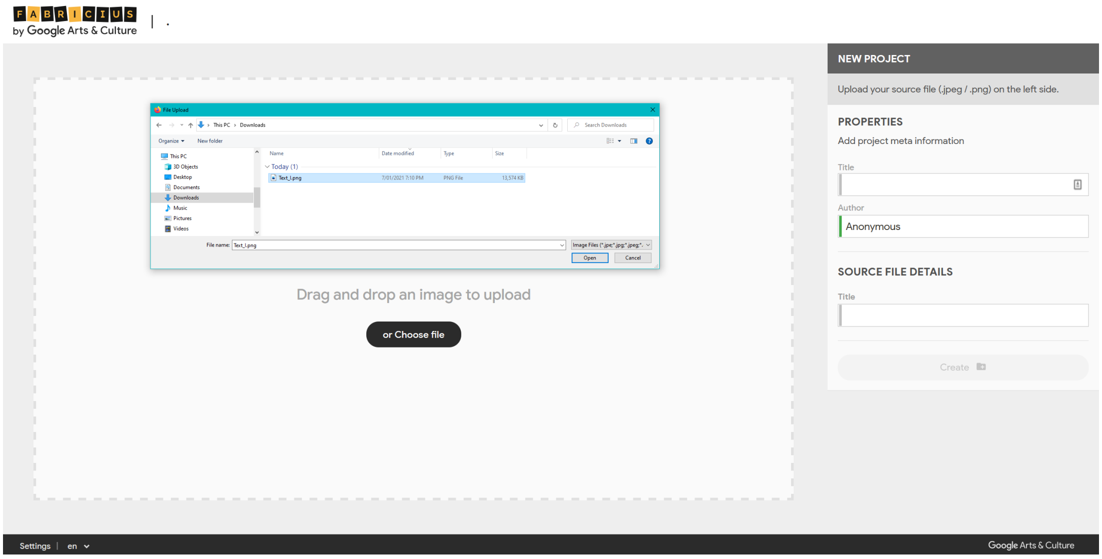

Figure 3.2: The *Fabricius Workbench*: starting a new project.

one process. The *Workbench* provides several tools, including an *Auto classify* function, which is designed to speed up the hieroglyph classification stage, and an *Auto translate*, which suggests word translations based on information from the *Thesaurus Linguae Aegyptiae* (*TLA*).[140]

The *Workbench* presents the user with five stages corresponding to various stages: *Process*, *Generate*, *Analyse*, *Annotate*, and *Properties*. The user can start a new project, import a project that has already been started, or watch a tutorial, which I created for Google Arts and Culture in early 2020.[141] To import a project, the user must have a *Workbench* project (saved in YAML format) already saved onto their computer.[142] If the user starts a new project, they need to upload a PNG or JPEG image file (the *Workbench* does not support other types of image files), provide a title for the project and an author name (Fig. 3.2). Selecting *Create* takes the user to the *Process* stage.

In the *Process* stage, the user has several tools to choose from, including *Select, Pan, Zoom in, Zoom Out, Reset zoom, Undo, Re-do, Layer opacities*, and *Create Marquee.* [143] In this first stage of the process, the user can select the area

[140] Personal communication with Alex Fry, Director at Psycle Interactive.

[141] Kelly, Ballsun-Stanton and Woods 2020b.

[142] YAML (.yml) stands for '*YAML Ain't No Markup Language*', and, according to the official website for YAML, is 'a human friendly data serialization standard for all programming languages' (see **YAML Ain't Markup Language** (YAML 2021)) YAML files are flexible and ideal for storing and transmitting data between applications. It achieves this by being compatible with all computer languages.

[143] Note: any inconsistencies in capitalisation are derived from the program itself.

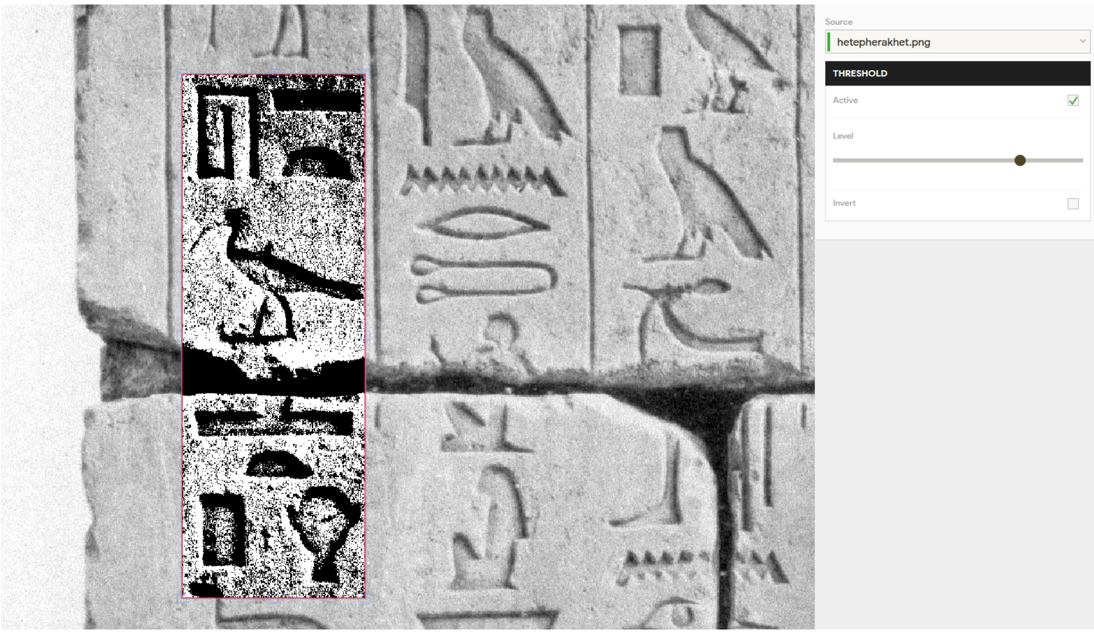

Figure 3.3: The *Fabricius Workbench*: adjusting the *Threshold* level.

of text they intend to work on by using the *Create Marquee* tool to highlight an area of the image by clicking and dragging. Once the user has selected the area they want, they must activate the *Threshold* function by ticking the check box on the right-hand side of the work area, which applies a thresholding algorithm to the newly created facsimile layer. Below the check box is a *Level* slider that adjusts the threshold intensity (Fig. 3.3).

Below this is another check box that activates the *Invert* function. The invert function is useful when the image the user is working with has a darker background which would result in a white-on-black image rather than the desired black-on-white one (Fig. 3.4).

In the *Generate* stage, the user has the same tools available as in the *Process* stage, with the exception that *Create Marquee* has been replaced with *Draw*, and *Erase*. Before the user can employ either of these new tools, however, they must activate the DRAW/ERASE function on the right-hand side of the work area. This panel contains two sections: TOUCH-UP, which contains the DRAW/ERASE option, and EFFECTS, which features the OUTLINES option. If activated, the OUTLINES option shows only the outlines of lines and shapes of the original image. The sensitivity of objects outlined can be adjusted using the *Level* slider available in this section.

Figure 3.4: The *Fabricius Workbench*: the *Process* stage shown with *Threshold* function activated (top) and *Invert* function activated (bottom).

It is in the *Generate* stage that the user can edit their facsimile layer and ensure that unwanted marks are removed, and that missing sections of hieroglyphs are restored. After activating the DRAW/ERASE option, the user can select either the *Draw* or *Erase* tools to edit their facsimile using the mouse to click and drag. The width of both the *Draw* and *Erase* tools can be adjusted using the *Width* slider in the DRAW/ERASE panel on the right-hand side of the work area (Fig. 3.5). Once the user is content with their editing and confident the program will be able to read their facsimile, they can proceed to the next stage: *Analyse*.

The *Analyse* stage offers the same tools again, however, in this stage, instead of *Draw* and *Erase*, *Create Marquee* is available again, along with a new tool called *Create Polygon*. The *Create Marquee* tool is used to select the hieroglyphs to be classified in this stage. The program determines the read direction based on where the user starts their selection. For example, clicking the mouse, then dragging the selection box down and to the right will result in the hieroglyphs being read from left-to-right, even if they are oriented from right-to-left. This is important to keep in mind when creating the *Marquee* selection during this stage.

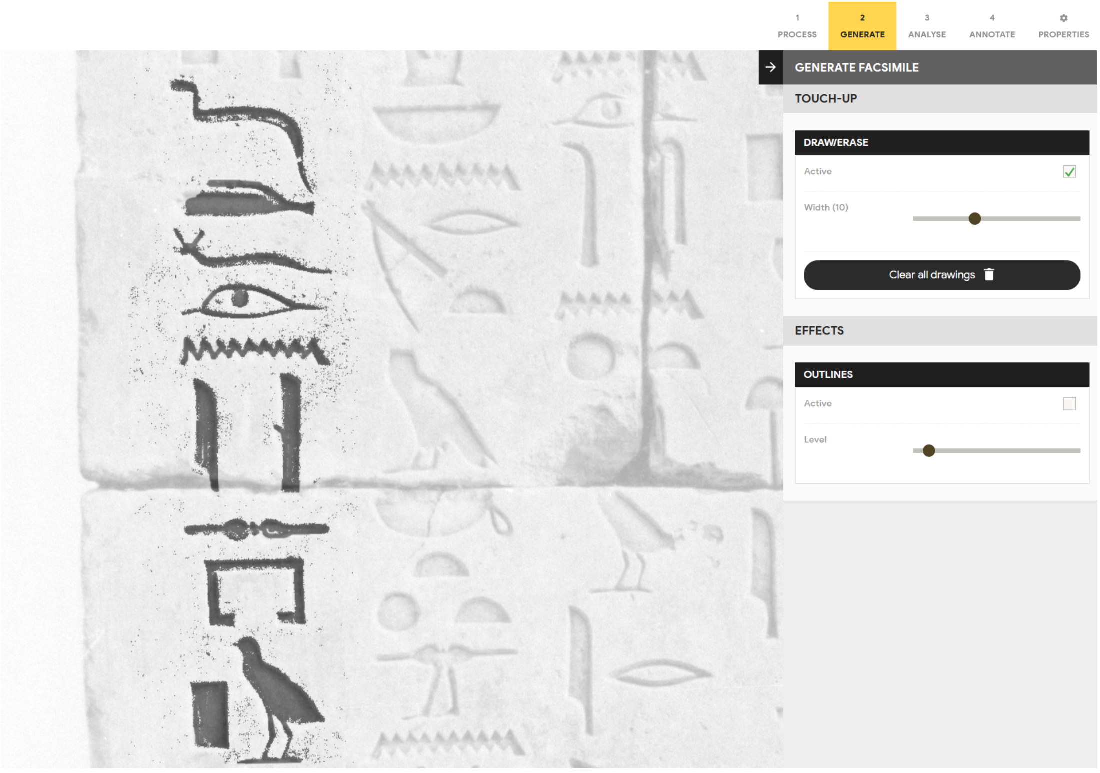

Figure 3.5: The *Fabricius Workbench*: the *Generate* stage is where the user can 'touch-up' their facsimile layer.

Using the *Create Marquee* tool to select multiple hieroglyphs will result in the program assigning them to *Words* and *Sentences* based on its interpretation of the positioning of the hieroglyphs. It is possible to select hieroglyphs individually using the *Create Polygon* tool, which requires the user to manually assign hieroglyphs to *Words* and *Sentences* as they make each selection. Rather than creating a rectangle selection like the *Create Marquee* tool, the *Polygon* tool allows the user to create multi-pointed shapes around individual hieroglyphs without overlapping other signs. The *Words* and *Sentences* appear in the *Sequence* panel on the right-hand side of the work area. The program also has the ability to identify cartouches, which are ovular shapes that surround royal (and occasionally divine) names.

Once the user has selected all of the hieroglyphs to be classified, they have the option to let the program attempt to classify the hieroglyphs for them. At the top right-hand corner of the *Sequence* panel is the *Auto classify* option, which can be selected for the whole selection, for each individual *Word*, or for each individual hieroglyph.[144] The program will return a top prediction, followed by a second and

[144]The *Auto classify* function can also be called the *Classify Glyph* function, but for the purpose of clarity and consistency, it will be henceforth referred to as the *Auto classify* function.

Figure 3.6: The *Fabricius Workbench*: the *Analyse* stage allows for hieroglyph classification and sequencing.

third prediction, for each hieroglyph, showing its Gardiner Code and an image of the hieroglyph (Fig. 3.6).

The user then has the option to adjust any incorrectly classified hieroglyphs by either selecting the correct one from the second or third predictions, or by clicking on the image of the hieroglyph visible in the *Sequence* panel and selecting the correct hieroglyph from the pop-up selection menu (Fig. 3.7). This menu is divided into the 27 hieroglyph categories established by Gardiner, accessible via a drop-down box. The user may also re-arrange the order of hieroglyphs within *Words*, *Words* within *Sentences*, or *Sentences* within the *Sequence* using the up and down arrows on the left-hand side of each item within the *Sequence* panel. They can also delete and re-select hieroglyphs, if necessary.

Once all hieroglyphs have been correctly classified and organised, the user can open the Translation panel visible at the bottom of the work area (Fig. 3.8). Here, the user can fill in the *Add translation*, *Add transliteration*, and *Add interpretation* fields using their own knowledge, or by referring to the *Auto translate* function in the *Translations* section at the bottom of the panel.

Running the *Auto translate* function will return suggested words using a

Figure 3.7: The *Fabricius Workbench*: the user can manually select hieroglyphs from the pop-up menu.

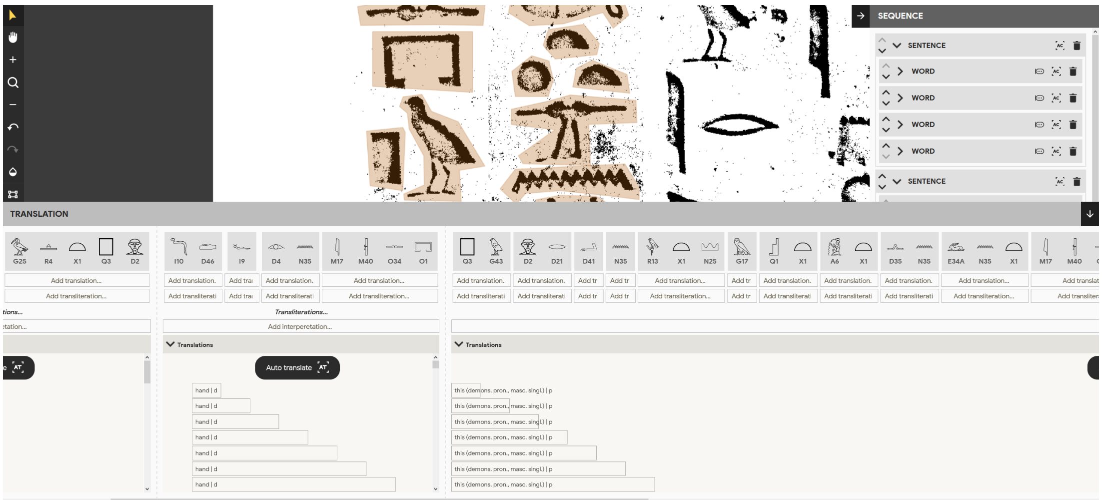

Figure 3.8: The *Fabricius Workbench*: the *Translation* panel offers fields for translation, transliteration, and interpretation, as well as an *Auto-translate* function.

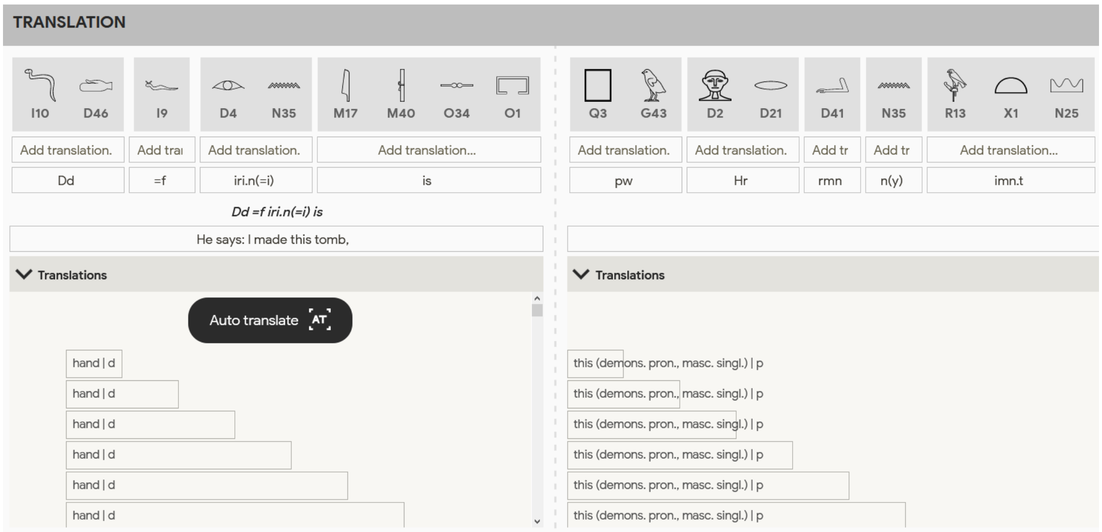

Figure 3.9: The *Fabricius Workbench*: the *Auto-translate* function suggests words based on the classified hieroglyphs.

specialised dictionary service created from material from the *TLA* (Fig. 3.9). Whilst the user can hover the cursor over these suggestions to highlight the corresponding hieroglyphs above, clicking a suggested translation does not input that suggestion into the translation field. The user fills in the transliteration, translation, and interpretation fields manually. The *Add transliteration* and *Add translation* fields correspond directly to *Words* within the *Sentence*, while the *Add interpretation* field spans the whole sentence and is the field in which the user can produce a running translation of the text. When the user has completed their translation, they can move into the *Annotate* stage to add notes to their project.

The *Annotate* stage contains an almost identical tool set to that available in the *Process* stage (*Select, Pan, Zoom in, Zoom Out, Reset zoom, Undo, Re-do, and Layer opacities*), but with *Create Marquee* replaced with only *Create Polygon*). However, this stage is primarily for making notes either for oneself or for other user to review once they have access to the project. The user can highlight specific areas of the image and attach notes to them by filling in the *Comment* field and selecting *Add comment* to save (Fig. 3.10). If the user has no more comments to add and wishes to save their project, they open the *Properties* stage.

The *Properties* stage is different to the other four stages. It allows the user to view and edit metadata, such as the project title and author (title can be edited while author is locked), view, add or delete source files, view glyph distribution information (Fig. 3.11), view project information (including the date the project

Figure 3.10: The *Fabricius Workbench*: comments can be used to communicate with colleagues.

was created and the last time it was edited), download the project facsimile as a PNG file, download the project itself as a YAML file, or delete the project altogether.

The *Fabricius Workbench* demonstrates how various digital tools can interact with each other to allow the user to review, edit, manipulate, and analyse hieroglyphs captured in digital format. Creating a system capable of performing all of these functions inevitably requires the knowledge of programmers, Egyptological linguists, and companies willing to fund the endeavour.

3.3.2 Recruitment

To advertise my case study, I sent an email to the Department of History and Archaeology at Macquarie University asking for interested parties to volunteer for the case study, and anyone in the department with appropriate candidates in mind were encouraged to pass along the invitation. I also made a post on *Twitter* calling for participants, which was then shared multiple times by members of the Macquarie University Department of History and Archaeology.

Eight volunteers responded to the advertisements and participated in the case study. Every other respondent in order or response was assigned to the B

Hide glyph distribution information (64)

x1	9
n35	7
d21	3
g17	3
m17	3
d2	2
i9	2
m40	2
o1	2
o34	2
q3	2
a1	1
a20	1
a40	1
a6	1
aa1	1

Figure 3.11: The *Fabricius Workbench*: the user can view how many times each classified hieroglyph, labelled with their Gardiner Code (left), was identified in their project (right).

group, thus groups A and B had an even number of four participants. I conducted a pilot case myself before commencing the case study with the participants to test the processes and questions I had prepared.

3.3.3 Ethics and Consent

As the project involved interacting with participants via video conferencing software, which involved being able to see inside parts of their personal living spaces, as well as the fact that the video conferencing sessions were recorded, ethics clearance and consent was obtained from all participants. Ethics clearance was granted on 07/07/20 by the Macquarie University Arts Subcommittee.[145] Following this, the ethics clearance and consent forms were sent to each participant, all of whom returned signed consent forms before the case study commenced.

3.3.4 Data Collection

To collect information on how effective the *Workbench* is in assisting the process of translating Hieroglyphic Egyptian, I was required to observe and record the participants interacting with the program. Before completing either translation,

[145] Reference Number: 17497 (Project ID: 6791).

I interviewed the participants about their expectations of the program going into the case study. Participants were asked to voice their thought processes whilst using the program so that I could gain an in-depth understanding of their experience. After participants had completed each translation, I interviewed them about their experience with the program. The notes collected from the interviews and my documentation of their user experience have been stored within a secure university-provided enterprise *OneDrive* folder to ensure there is a form of back up, as well as regular backups taking place through use of version control.

The data collection framework employed in this methodology has been modelled after the case study of Tamar Sadeh (2008) regarding user experience of a library search system interface.[146] Sadeh's study investigated the experience of users interacting with the search system interface of the library in question and used the information gathered to inform a new model of search system interface that was based on already existing systems in order to better satisfy user needs. The present case study aimed to use a similar approach to develop a theoretical model for technological tools and how they can be incorporated into Egyptological research.

3.3.5 Texts

The texts chosen for the participants to translate were the tomb-chapel inscription of Hetepherakhty from the Old Kingdom, and the Middle Kingdom stela of Mentu-woser. Both of these texts were suited to be tested in the *Fabricius Workbench*, as both contain typical linguistic constructions of their text type, namely a funerary text and a memorial text. In other words, they contain predominantly formulaic sentences and concepts that are easily recognisable by Egyptologists who have studied at least two semesters of Hieroglyphic Egyptian (the minimum requirement for participants of this case study). Another consideration when selecting texts was that images of the texts had to be available in a high enough resolution for the *Workbench* to process.

The first text chosen for translation in this case study was the inscription of Hetepherakhty, 'elder judge of the hall' from the Old Kingdom.[147] The inscription

[146] Sadeh 2008.
[147] Lichtheim 2006, 16.

chosen for testing can be found on the right-hand side of the entrance to the tomb chapel of Hetepherakhty's tomb, held at the National Museum of Antiquities in Leiden, Netherlands.[148] It consists of four columns of text and is typical of an Old Kingdom (c.2687 – 2190 BCE) funerary text, eulogising the owner of the tomb and describing his position in life.[149] A translation of this section is available in Miriam Lichtheim's anthology.[150] Hetepherakhty's inscription contains easily identifiable linguistic features, including the nominal verb form of the present perfect *sḏm.n⸗f* in *iri.n(⸗i) is pw*, which can be taken as denoting an emphatic construction (i.e., 'That I made this tomb is...').[151] This clause also contains a known masculine singular adjectival demonstrative, which is something students of Hieroglyphic Egyptian are introduced to early on in their studies.[152]

Text II, a memorial stela positioned on the processional route in Abydos for Osiris, belongs to the steward Mentuwoser from the Middle Kingdom.[153] The stela depicts the deceased official Mentuwoser receiving food offerings from his family and is currently on display at the Metropolitan Museum of Art, New York (accession number 12.184).[154] The text of the limestone stela is in sunk relief while the images below the text are carved in low-relief and painted. Mentuwoser's stela dates the reign of Senwosret in the Middle Kingdom (c. 2000–1650 BCE), and like Hetepherakhty's inscription, describes to the reader who the man was, what his position was, and all the good things he did during his life.[155] The section of text selected for the case study starts with a date, which is easily recognisable by any Egyptologist, as well as the common offering formula known as *ḥtp ḏi nsw* ('A gift which the king gives'), which also features honorific transposition.[156] Both texts also contain names and titles, which are accessible to Egyptologists via name and title lexica.[157]

[148] van de Beek 2017.
[149] Verner 2001, 585.
[150] Lichtheim 2006, 16.
[151] Ockinga 2012, § 71.
[152] Ockinga 2012, § 29; I am referring to the Macquarie University curriculum and textbook (Ockinga 2012) as a paradigmatic case, as six of the eight case study participants studied there.
[153] The Metropolitan Museum of Art 2021.
[154] The Metropolitan Museum of Art has released several publications about or including the stela: see **THE MET | Stela of the Steward Mentuwoser** (The Metropolitan Museum of Art 2021).
[155] Franke 2001, 393.
[156] Ockinga 2012, § 10, 41; Allen 2010, 366.
[157] Hannig 2006, 1281–1314; Jones 2000.

3.3.6 Observation

Observation sessions and interviews were conducted over the internet using the video conferencing program *Zoom*, which allowed for flexibility and the ability to conduct the sessions remotely. It also allowed the observation and interview sessions to be recorded on my local computer and then reviewed after the fact for note-taking. Using *Zoom* also allowed for screen-sharing, which enabled me to view participants' actions within the *Fabricius Workbench* while they talked me through their thought processes. The participants were instructed to articulate their goals and intentions and which tools within the program they believed would achieve them.

A structured format was prepared prior to observation, providing a framework for what was to be recorded during observation. Time taken to complete a task was also recorded, as well as any errors, whether they were human error or design based, how often the participant needed to refer to external material, such as a printed dictionary, when using the *Workbench*, and at what stages of the process these occurred.[158] It was noted whether the actions taken resulted in the desired outcome based on the participant's goal.[159]

3.3.7 Pre-use Semi-structured Interview

Before the first observation session, participants were interviewed to establish their level of experience with both translating hieroglyphic texts and using digital tools in research. This interview was conducted over *Zoom*, with the recorded video file being stored as data for reference and review.

Questions:

1. What is the highest level of tertiary education that you have achieved? In what year?

2. What experience do you have with the translation of ancient Egyptian hieroglyphic texts?

[158] Norman 2013, 5.
[159] C. Lewis *et al.* 1990, 236.

3. What digital technologies have you personally used in your studies or research in Egyptology over the past 12 months?
4. How familiar are you with the selected text?
5. What does your preferred method of translating hieroglyphic texts entail?
6. What frustrations do you experience with your preferred method?

3.3.8 Manual Translation

Observation of the manual translation process required the participant to walk me through each step and thought process and explain why each decision was made (such as referring to a particular dictionary or grammar book). I took notes to record the steps taken to complete the translation process manually, as well as annotations that elaborate on the participants' thought processes and justifications for actions. Participants were asked to send their final translations and notes to me to further enrich my note-taking.

3.3.9 Translation using the *Fabricius Workbench*

Before commencing the observation session where the participant was asked to translate a selected text using the *Fabricius Workbench*, they were be given an introduction into how the program operates through a pre-recorded demonstration video.[160] This video showed the participants what the program looked like, what tools were available, how they could be used, and the step-by-step process of the *Workbench's* design. I answered questions following the introduction but kept interference from myself as the observer to a minimum during the observation session.

The focus of these observation sessions was to note whether the participant could effectively learn the function and application of the *Workbench's* tools (e.g., *Create Marquee* tool, *Threshold* function). If the participant encountered an obstacle and needed assistance to move on with the translation, it was noted in what way the program failed to make the next step self-evident.

[160] Kelly, Ballsun-Stanton and Woods 2020b.

3.3.10 Post-Use Semi-structured Interview

The post-observation questions were designed to capture the user experience of the participants, as well as their interpretation of the interaction between digital technology and trained researchers of Egyptology. These interviews were conducted following the final observation session using *Zoom*, with the recorded video file being stored as data for reference and review. The participants also shared their *Workbench* project files with me for further review.

Questions:

1. What *single* aspect of the *Fabricius Workbench* did you find helped the translation process the *most*?
2. What *single* aspect of the *Fabricius Workbench* did you find helped the translation process the *least*?
3. What *other* aspects of the *Fabricius Workbench* did you find *helpful* towards the translation process?
4. What *other* aspects of the *Fabricius Workbench* did you find *not* helpful towards the translation process?
5. What *benefits* do you perceive in using the digital format?
6. What *limitations* do you perceive in using the digital format?
7. In what ways can the *Fabricius Workbench* be *improved* in order to be a useful digital tool for translation?

3.4 Outcomes

A summary of the results of the case study can be found in Chapter 4, and the implications of what was found are discussed in Chapter 5. Specifically, Chapter 4 considers participants' answers to the interview questions, their experiences using the *Fabricius Workbench* and ideas for future developments, as well as how accurately the auto-classify function performed.

Chapter 4

Case Study Outcomes

Each of the eight participants were asked to complete two interviews and two translations for this case study. The conducted interview before either of the translations aimed to establish the perceptions participants held towards digital tools and the *Workbench* itself (§ 4.1), while the interview conducted after both translations aimed to find out how the participants' perceptions had changed over the course of the case study (§ 4.4). Participants completed one manual translation of a text (§ 4.2), and one using the *Fabricius Workbench* (§ 4.3). The results are outlined below.

4.1 Pre-use Semi-structured Interview

Before commencing the case study, participants discussed their expectations for the *Fabricius Workbench,* and many were excited to see what the program had to offer. All participants also admitted to feeling sceptical about how much the *Workbench* could improve the practice of translating hieroglyphic texts. Several of the participants noted that those who already have an established method of translating would have to learn a new process, which could impede the adoption of something like the *Workbench* as an 'improvement' to the research process. The questions for this interview were designed to establish the participants' level of experience with translating ancient Egyptian hieroglyphic texts, their experience with digital technologies, and their usual methods of translating in order to contrast with their experience with the *Workbench.*

Participant education level ranged from postgraduate student to university professor and career researcher. Six of the candidates had achieved at minimum a Bachelor of Ancient History or Arts majoring in Ancient History, a Master of Research, or Graduate Certificate in Ancient History from Macquarie University. Two of the candidates were from overseas, namely, Egypt and the Netherlands, and both of these candidates had achieved PhDs in Egyptology. Experience translating Hieroglyphic Egyptian ranged from one year to over ten years. Most participants had studied hieroglyph Egyptian as part of their university education and the more established academics actively used it in their research.

All participants expressed that they make use of a computer for their studies or research. They use a variety of computer programs, hieroglyphic fonts and text editors, and online resources, including *Microsoft Word*, *Microsoft Outlook*, web browsers, *Zoom*, *JSesh*, *EZ Glyph*, *Trlit_CG Times*, *Thesaurus Linguae Aegyptiae* (*TLA*), *The Hieroglyphica Project, Online Egyptological Bibliography* (*OEB*), *Ramses Online*, and the *Deir el-Medina Database*.[161] Participants noted that in the time of Covid-19, they have had to rely on their computers more than usual for study.[162] This involves the introduction of online teaching and studying using video conferencing programs like *Zoom*, and a reliance on email programs like *Microsoft Outlook*.

When it came to translating hieroglyphic Egyptian texts, many participants expressed that they preferred to write out their preliminary transliteration and translation on paper and would later type up a 'neater' version on their computer, usually in a *Microsoft Word* document. This practice also makes it easier to share work and progress with colleagues or teachers, as text documents can be easily sent via email. Services like *SharePoint* can also serve this function, and this was the method by which participants were given access to the *Workbench*, the tutorial, and the images of the chosen texts.

Three of the participants felt that they had possibly seen Text I before, but were unsure, two had seen the text before, but had not translated it, and one had interacted with the artefact on which the text appears and translated parts of the

[161] Rosmorduc 2014; Museum Tours 2021; The Deir el-Medina Database 2021; BBAW - Ancient Egyptian Dictionary Project 2021; Panov 2021; Griffith Institute 2021; Université de Liège 2021; Donker van Heel *et al.* 2018.

[162] Anderson 2020.

text years earlier. One had never seen nor heard of the text at all. Three of the participants were familiar with the format of Text II but had not translated this specific text, and two had translated some parts of the text, but these sections were not included in the selection on which the participants were being asked to focus. Three participants had never seen nor heard of this text before. Regardless of their level of familiarity with a text, all participants described their approach to manual translation in the following steps:

1. Determine direction of text
2. Write out transliteration or phonetic value of known hieroglyphic signs
3. Look up unknown/unfamiliar hieroglyphic signs and add to transliteration
4. Write out translation/possible translations of known words and phrases
5. Look up unknown/unfamiliar words and phrases and add to translation
6. Identify known grammar
7. Look up unknown/unfamiliar grammar
8. Generate translation

Despite having this established process for translating, six participants admitted they find the activity time consuming, which was something that Ubisoft and Psycle sought to address when pitching the *Fabricius Workbench*.[163] It was noted that it is often difficult to find a high-quality image of a desired text. This lack of imagery could be due to early publications only being available as physical copies, not being published at all, having no digital copies available or accessible, or not providing enough details published to be able to track down certain images.

In addition to the difficulty of finding high-quality images, texts often suffer from damage, whether intentionally inflicted during antiquity or a result of deterioration over time, Egyptologists need to either reconstruct missing sections or work around them. Additionally, tackling the complexity of grammar of hieroglyphic Egyptian script is often the most challenging aspect of translating. In fact, there are often multiple possible interpretations of the same phrase or

[163] Google Cloud 2018, 1:25:00-1:29:55.

sentence, as there is no single correct translation. One participant pointed out that there is also no single standard transliteration system for hieroglyphic Egyptian.[164] For example, where a British Egyptologist might translate the sign Z4 as 'y', a German Egyptologist would translate the same letter as 'jj', or M17 as 'i' as opposed to 'j',or O34 as 's' as opposed to 'z'.[165] All participants employed the British transliteration system.

The case study investigated whether the *Fabricius Workbench* could highlight aspects of the translation of Hieroglyphic Egyptian that might be improved by developing one or more components of the program. In order to do this, the participants completed a manual translation of one of the chosen texts while I observed and took notes on their methods.

4.2 Manual Translations: Group A Translation of Text I and Group B Translation of Text II

The time taken to complete Text I ranged from two to two and a half hours. Three participants of Group A completed the translation while one decided to end the session leaving the translation unfinished. Time taken to complete Text II ranged from one hour to one and a half hours. Two participants of Group B completed the translation during the session. Two participants of Group B were unable to participate in this translation session.

Two participants chose to complete their translation using pens and paper. One utilised coloured pens, each colour representing a different kind of annotation. Four participants typed up their transliteration and translation in a *Microsoft Word* document using a transliteration font. All participants had the image of the text open in an image viewer in order to zoom in to certain sections of the text and inspect individual hieroglyphs more closely. One participant also printed out a hard copy of the text to annotate.

All participants supplemented their knowledge with physical Egyptian grammar books and dictionaries. Five participants utilised Raymond Faulkner's (1962)

[164] Allen 2010, 13.
[165] Gardiner 1957, 481, 496, 536-7.

dictionary; one used the grammar and sign list of Alan Gardiner (1957), and two used the German Egyptian dictionary by Rainer Hannig (2006). All except one of the participants used the grammar by Boyo Ockinga (2012). Two participants consulted Miriam Lichtheim's anthology with the translation of the text (2006:16).[166]

Three participants had pdfs of reference works accessible on their computers: one had the title lexicon by Dilwyn Jones (2000) open in a pdf reader, another had a 'modernized' version of Faulkner (1962), made available in 2017 by Boris Jegorović, and the other had a pdf copy of the *Wörterbuch der ägyptischen Sprache* (1926–1931) by Adolf Erman and Hermann Grapow (eds.).[167] Three participants also had the *TLA* open in a web browser. One participant made use of the hieroglyphic text editor *JSesh* to check the forms of the hieroglyphs. This participant noted that utilising different resources in their process (*TLA*, Faulkner, Hannig, etc.) allows for the most informed transliteration and translation.

From observing the participants' translation methods, it became evident that while much of the process utilised the participants' own knowledge, many resources were consulted, including physical and digital copies of dictionaries, lexica, and grammars, as well as computer programs that allowed them to type up their transliteration and translation in a digital format, ready to share with colleagues. In fact, each participant emailed the *Microsoft Word* document of their transliteration and translation to me immediately following their observation session, and this allowed me to combine the information provided therein with my own notes, thus enriching the output of each session.

In order to contrast their usual translation method with one that involves the *Fabricius Workbench*, the participants translated the other chosen text by uploading an image of it into the *Workbench* and engaging with the five stages to produce a translation.

[166] Faulkner 1962; Gardiner 1957; Hannig 2006; Ockinga 2012; Lichtheim 2006.
[167] Jones 2000; Jegorović 2017; Erman and Grapow 1926–1931.

4.3 Translations using the *Fabricius Workbench*: Group B Translation of Text I and Group A Translation of Text II

Time taken to complete Text I using the *Fabricius Workbench* ranged from two hours to four hours and twenty minutes. Time taken to complete Text II using the *Fabricius Workbench* ranged from one and a half hours to two hours. None of the participants in Groups A nor B completed the translation during the session.

Most participants were able to start a new project in the *Fabricius Workbench* without much prompting. Tools like *Zoom in*, *Zoom Out*, *Pan*, and *Select* were utilised by most participants intuitively and without much prompting, although six participants did find that most of the program's interface was not self-explanatory. Using the *Create Marquee* tool to select a portion of the text was completed intuitively by five participants. The need to activate the *Threshold* function was not initially self-evident, although most participants did recall this step from the tutorial. Two of the participants found the adjuster for the *Threshold* level too sensitive.

After first attempting to find their desired level of *Threshold*, Participant007 opened a *Microsoft Word* document to transcribe the hieroglyphs using a specialised hieroglyphic font that offers both transliteration and hieroglyphic signs called *EZ Glyph*. They used a *Snipping Tool* image of that as input for the *Workbench*, as it would theoretically be easier for the program to read and eliminates the need to manually edit the hieroglyphs. As the image transitioned from *Microsoft Word* to the *Snipping Tool* to the facsimile layer of the *Workbench*, it became less clear, as seen in Figs. 4.1 and 4.2. This affected the program's ability to recognise the hieroglyphs during the auto-classify process.

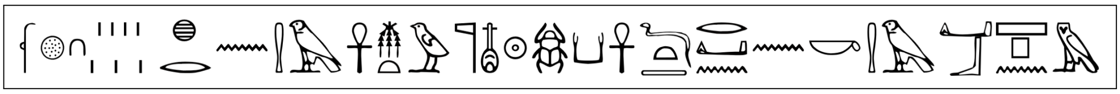

Figure 4.1: Participant007's 'in-between cheat step' transcription in *Microsoft Word* using *EZ Glyph* font.

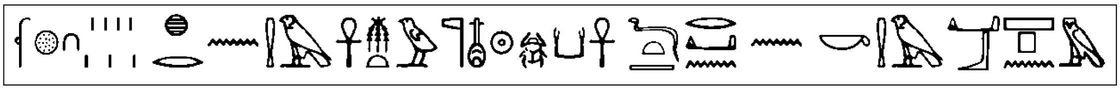

Figure 4.2: Participant007's 'in-between cheat step' transcription after applying the *Threshold* layer in the *Workbench*.

All participants found that the *Workbench* would begin to lag badly in the *Generate* stage. One participant noted that the facsimile layer creation process takes a long time to complete, and the tools in this stage were less self-explanatory than in the *Process* stage. None of the participants found the *Outlines* function useful for this task. The *Layer opacities* function was utilised by four of the participants to view the image beneath the facsimile layer to guide their drawing and editing, while the other four participants did not find it necessary.

One participant noted that they felt they needed to stop adjusting the width of the drawing in order to save time, rather than waiting for the program to reload each time a different width was selected. They also preferred to erase errors rather than using the *Undo* function, as this also took a long time to process. The program lagged increasingly over time for all participants and the *Draw/Erase* tools would sometimes stop functioning altogether. All participants found that they became faster at drawing and erasing as they familiarised with the process, however, the program could not keep up with them. It was noted that if the user were to draw with pen and paper, they would be able to create more complex shapes, while in the *Workbench*, the user needs to make small, short, straight lines, as it responds better to these than long or curved lines.

In the *Analyse* stage, most participants used the *Create Marquee* tool at first when selecting hieroglyphs for classification, however, most decided to use the *Create Polygon* tool for the majority of the selection process. The *Create Marquee* tool often resulted in other hieroglyphs nearly being deleted, as sections delineated by the *Create Marquee* tool cannot overlap. The *Create Marquee* tool also often resulted in the mis-assignment of hieroglyphs. For example, during one participant's session, the program recognised one of the hieroglyphs, missed the other, then ‘identified’ several small particles of visual noise that had not been erased. It then assigned these approximately 18 ‘hieroglyphs’ into three separate words and assigned one as a cartouche. All of this sequencing was incorrect and had to be rectified by the participant using the *Create Polygon* tool to carefully assign the hieroglyphs correctly in the *Sequence* panel.

All participants had to be guided through this process of assigning hieroglyphs to words and sentences in the *Sequence* panel, although one participant did become adept quite quickly. All participants consulted resources like Ockinga (2012), Hannig (2006), and personal notes on grammar, to help them determine the correct sequencing of the hieroglyphs. One participant noted that this stage of the process does encourage the user think in-depth about the hieroglyphs they are working with and how they should be organised.

Six participants chose to apply the auto-classify function word by word and two applied it all at once. The latter option sometimes caused the program to slow down or return an error. As evident in Table 1, one participant received a success rate of 100%, however, this result is highly misleading as this participant had only selected two hieroglyphs for classification. Another participant achieved 50% with eight hieroglyphs, and another 11.11% with nine hieroglyphs. It is important to note that the clarity of the facsimile layer created during the *Generate* stage plays a key role in the program’s ability to identify the hieroglyphs represented. Participant007’s theory that using an image of hieroglyphic font as input for the *Workbench* would greatly increase the program’s ability to achieve a higher accuracy rate of auto-classified hieroglyphs was ultimately correct. The ‘in-between cheat step’ achieved an accuracy rate of 51.22%, an improvement on the 14.29% of their other edited facsimile layer. However, 51.22% is still not a sufficiently high rate of accuracy for the tool to be useful and the participant had to correct several mis-classified hieroglyphs.[168]

Once all selected hieroglyphs were correctly assigned, participants had the option to auto-translate their sentences, which all participants did. They all found that the program did not identify all of the selected and assigned hieroglyphs and

[168] Due to wanting to save time, participant007 chose to only select 14 hieroglyphs when creating a facsimile layer from the original image of the text as compared to the 41 they were able to generate using *EZ Glyph*, the facsimile layer of which they did not edit at all during the *Generate* stage.

Participant	Group	Text	Total Hieroglyphs	Correct	2nd Choice	3rd Choice	Incorrect	% Correct
001	A	I	41	8	3	1	33	19.51219512
002	B	II	64	15	3	2	49	23.4375
003	A	I	9	1	1	2	8	11.11111111
004	B	II	8	4	1	0	4	50
005	A	I	28	4	1	1	24	14.28571429
006	B	II	2	2	0	0	0	100
007_1	A	I	14	2	2	1	12	14.28571429
007_2	A	I	41	21	2	0	20	50.2195122
008	B	II	11	3	1	0	8	27.27272727

Table 1: Rate of accuracy of *Auto-Classify* function of *Fabricius Workbench*.

provided multiples of the same translation suggestion. All of the participants felt that the program had skipped over or failed to identify hieroglyphs and words that commonly appear in texts. All participants relied primarily on their own knowledge and external resources, including Ockinga (2012), Hannig (2006), and Faulkner (1962) to produce their translation.

Half of the participants found the organisation of the *Add Translation*, *Add Transliteration*, and *Add Interpretation* fields of the *Translation* panel appealing. The other participants, however, found this layout counter-intuitive, as they felt that the transliteration and translation fields would normally be in the reverse order, with transliteration above translation, as in the *Microsoft Word* documents generated from their manual translations.

All participants except for one were instructed on how to add comments to their project in order to communicate with anyone with whom they wished to share their work. Participants were talked through the process of downloading their project as a YAML file to send via email for review and all completed this task with no issue.

All participants experienced at least one software error during their translation session. Participant002 received eight errors, while the other seven received between one and three. Errors ranged from the web browser tab crashing when processing, the program getting stuck on a loading screen between stages, to issues regarding processing selection or auto-classification of hieroglyphs. Most errors occurred during the *Analyse* stage.

After completing their translation using the *Fabricius Workbench*, each participant was interviewed about their experience and how their perspective of the program has changed. All participants admitted that they were less optimistic about the program's acceptance as an example of a digital tool for epigraphy or for translation than before using it, and so they were asked to provide feedback on how the components of the *Workbench* might be improved.

4.4 Post-use Semi-structured Interview

All eight participants expressed many frustrations with the *Fabricius Workbench* but provided suggestions for potential improvements or ways in which the *Workbench* could inform the development of future digital tools. They were asked to identify the most and least useful aspects of the *Workbench*, as well as the benefits or limitations of using digital tools in research.

Multiple participants discussed the concept of self-containment, regarding both the *Translation* panel with the translation, transliteration, interpretation, and auto-translate fields laid out one below the other, and the program itself, with the original image, facsimile layer creation, hieroglyph classification, and translation tools contained within one program. This aspect, if optimised, would reduce the need to search external resources when translating words.

The aspect of the *Workbench* that all participants experienced the highest level of difficulty with was the process of the facsimile layer creation in the *Generate* stage. Participants found the process slow, time-consuming, and difficult to complete with the level of accuracy they desired. It was described by more than one participant as 'needlessly tedious and frustrating'. Two participants stated that they had not found the program useful at all, particularly noting the lag it experienced.

Several participants stated that the process of drawing over the hieroglyphs helps the user familiarise themselves with the signs, focus on them, and think about what they are. It also allows the user to repair and reconstruct hieroglyphs, although this aspect is also problematic, as the term 'facsimile' has a specific meaning in Egyptology. One participant highlighted that the program does not 'do justice' to the process and skill of creating a 'true' Egyptological facsimile but rather creates an image to work from. Furthermore, as the user is actively changing the hieroglyphs that are represented in the text, the use of the word 'facsimile' is misleading, as Egyptological facsimiles aim to preserve the exact state of the text as it appears at the time of the facsimile creation.

The auto-classify and auto-translate functions were also deemed to be unhelpful to the translation process. The auto-classify function was not nearly accurate enough to reduce the time taken identifying hieroglyphs, and the auto-translate function either returned several repeats of the same suggested translation or skipped over hieroglyphs entirely. It was noted that the program does not take word order or any grammatical aspects of the text into consideration, which is a vital component of translation.

When correcting the mis-identified hieroglyphs of the *Auto classify* function, the ability to search the hieroglyph by phonetic value or Gardiner Code, as is possible in *JSesh*, would improve the efficiency of this step, as well as being able to copy and paste duplicate signs, rather than manually selecting each and every one. The colour coding of the word and sentence selection process also needs to be more self-evident. At present, it shows grey for 'not selected' and dark grey for 'selected'. It also sometimes de-selects the word or sentence the user had selected when they start dragging the *Create Marquee* tool. As a result, the contents of the *Sequence* panel become difficult to keep track of during this stage.

The auto-translation section would need to be able to provide the various potential phonetic values for hieroglyphs, as some have multiple different phonetic values that are determined by context – which the program does not take into consideration. A space for adding grammatical notes and annotations in the translation phase was also suggested.

It would be beneficial if the program could take the context and genre of the text into consideration, as well as other background information that could inform its suggestions and help it prioritise suggestions. This could include grammatical constructions, common phrases, and epithets. Prioritisation could also be based on grammatical conventions and word boundaries. Where the program does not immediately identify a common construction, such as the *ḥtp-ḏı -nsw* offering formula, the participant suggested being able to link the three components together in the translation stage, rather than having to return to the classification stage to re-assign hieroglyphs to separate words or sentences. The ability to re-arrange the hieroglyphs and words in the translation stage rather than the classification stage was highlighted by more than one participant.

When asked to reflect on the benefits of digital technologies more generally applied to research, participants identified accessibility as one of the key benefits. Internet access enables file sharing, and distance communication and study, allowing collaboration to occur between colleagues from completely different countries. Having resources consolidated into a single environment can also reduce switching between resources, and can streamline practices like epigraphy, where steps like tracing are moved to the computer or digital drawing tablet. Digital versions of documents can also often allow searching within their text, which is particularly useful when consulting a dictionary.

Digital technologies have their limitations as well. The benefits of internet connectivity can only be enjoyed when one has electricity and access to an internet connection, which can be limited by economic factors. As discussed in § 2.3, the longevity of software and online sites can become an issue if they are not maintained or become redundant after some time. Digital tools can also be difficult to introduce into fieldwork, due to practical reasons. They rely on access to electricity, and can be affected by the environment, including vulnerability to sand and sun exposure. It is still essential to be able to work with manual methods. Many researchers have worked with the same processes for up to decades and are thus not ready for a move towards the digital format at any stage of their process. Digital technologies such as software and programs are often owned by specific institutions, organisations, or companies and can cost money to access or obtain. This is one advantage of something like the *Workbench*, as it is open source.

4.5 Results Summary

Having observed eight Egyptologists of varying levels of experience complete a manual translation of a text and one using the *Fabricius Workbench*, it is evident that translating Hieroglyphic Egyptian is an established process that the program itself did little to improve. Nor did it highlight aspects of the process that are currently lacking. However, it did demonstrate that Egyptologists are interested to see what digital technologies for research might look like. Although they overall deemed the *Workbench* unhelpful, the participants expressed an interest in seeing components of it improved and applied in different ways. Many liked the idea of digitised data, where transcribed hieroglyphs are linked directly to the source image of a text, and the transliteration, translation, and possibly even grammatical and contextual notes are all linked together in a single file that can be analysed, edited, and shared among colleagues.

Chapter 5

Discussion

The following chapter aims to discuss the outcomes of the case study (§ 5.1), outlined in Chapter 4. As the interests of the stakeholders might have had an impact on the trajectory of the *Fabricius* project, it is important to evaluate whether this was reflected in the outcomes of the case study (§ 5.2). The case study outcomes are then analysed using a SWOT (strengths, weaknesses, opportunities, threats) framework (§ 5.3) in order to determine the potential outcomes of this thesis (§ 5.4). Three primary outcomes were identified: exploring how the components of the *Workbench* might be improved (§ 5.4.1), hypothesising projects designed for teaching new skills to students of Hieroglyphic Egyptian (§ 5.4.2), and further exploring the importance of encoding hieroglyphic data in a way that is universal and transferable (§ 5.4.3).

5.1 Discussion of Case Study Outcomes

The first of the research questions posed in Chapter 1 asked:

> How useful is the *Fabricius Workbench* in translating Hieroglyphic Egyptian?

This research has revealed, on the basis of the first user-based study, that the *Fabricius Workbench* did not perform in the manner expected. It did not speed up the translation process and in fact, it more often slowed it down and made it more tedious. Although this slowness can be partly attributed to the fact that the case study participants were unfamiliar with the program, it must also be acknowledged that lag and delays were also experienced in my own interactions with the Workbench, despite my familiarity with the program. That is not to say, however, that researchers and developers cannot build on its attempt to create a useful digital tool for the Egyptological community.

The *Auto classify* function, which is the only component of the program that employs machine learning, suffered from a low accuracy rate and was of little use to the case study participants. The accuracy of this function could be improved with larger, more refined training sets for the machine learning model; however, this begs the question: would it address a need that Egyptologists have? While Egyptologists may not benefit from an auto-classification tool for preparing a translation, machine learning could assist in automating the process of marking up large amounts of texts for digital corpora. Rather than focusing on applying it to the process of translation, the conversation needs to shift towards recording hieroglyphic data digitally. Thus, by isolating the components of the *Workbench* that can address the need to digitally capture hieroglyphic data in a meaningful way and improving on those, we can achieve more practical outcomes for research.

The four main components of the *Workbench* include the facsimile layer creation process, the sequencing process, the *Auto classify* function, and the *Auto translate* function. The facsimile layer creation process lagged the most of all of the *Workbench* components and took the most time and effort to navigate and complete. This component relates more to epigraphy than to translation as it loosely reflects the work of digital epigraphers, who trace over a scaled-down photo enlargement of a wall scene using a digital drawing tablet and stylus pen.[169] The latter method offers the user far more customisable drawing and erasing tools than those of the current iteration of the *Workbench*.

Participants found the facsimile layer creation process the most tedious stage of using the *Workbench*. The program consistently crashed and experienced various errors during this stage and there was often a disconnect or lag between the user's input and the program registering their input. Despite the issues experienced during this stage, the user cannot skip the facsimile layer creation and move on to later stages if they want to utilise the *Auto classify* function. If the user were to manually classify all of the glyphs, then the facsimile layer creation stage

[169] Vértes 2014, 88, 98.

would not be crucial to the user. However, the *Workbench* is currently designed to require the facsimile layer, as selections cannot be made during the *Analyse* stage if a facsimile layer has not been created, and thus the user would not be able to interact with the image in order to complete the classification.

The sequencing process takes place when a user selects a number of hieroglyphs in the *Analyse* stage using the *Create Marquee* tool. The program identifies and records where the hieroglyphs are located on the facsimile layer and uses this information to organise the hieroglyphs into a sequence. Most participants found that the program did not correctly identify the sections of their facsimile that correspond with the hieroglyphs being represented. Instead, the program would highlight different sections of single hieroglyphs and count them as two different hieroglyphs, mistakenly identify a group of hieroglyphs as being within a cartouche, or highlight the tiny specks of visual noise that the participants had either intentionally or unintentionally not erased during the *Generate* stage. This stage required a lot of manual selection using the *Create Polygon* tool and manual assignment of hieroglyphs to words and sentences in the *Sequence* panel, which added time to the overall process.

The *Auto classify* function identifies the hieroglyphs selected during the sequencing process by accessing a machine learning model through Google's *Cloud AutoML* service and assigns them each a Gardiner Code. This function was the least useful for the case study participants, as it achieved an average accuracy rate of 26.39% (disregarding participant006's results, see § 4.3, Fig. 1). The process required the participants to manually select the correct Gardiner Code for most of the hieroglyphs, which took far more time to do using the *Workbench* than when identifying them during their manual analysis.

The *Auto translate* function was also of limited use to the case study participants, but the overall concept and design were received positively. The idea of including a component of the program that helps the user access online dictionary services appealed to most participants, and the fact that the translation suggestions were available within the working window meant that if the suggestions were accurate, the user would not need to switch windows or consult a large number of physical resources for their translation. The *Auto translate* function, however, did not offer accurate nor helpful suggestions, as it focused on one hieroglyph at a time, rather than using the *Word* delineations to eliminate irrelevant suggestions. For example, one user had assigned the hieroglyphs 𓊪 (Q3) and 𓅱 (G43) as a *Word*, being ‘pw’. The *Auto translate* function offered several iterations of the same suggestion for the p, being ‘this (demons. pron. masc. singl.) | p’, identifying that p by itself can be translated as the singular masculine demonstrative ‘this’. However, this is not a useful suggestion, as the user was not looking for a translation of ‘p’, but of ‘pw’. The program then skipped the 𓅱 altogether, offering no suggestions at all and moved straight to the second hieroglyph of the following *Word*. It appears that the *Auto translate* function looks up each hieroglyph independent of those around it and does not seem to take the *Word* designations into consideration. Even if the function were to look up each word as a whole (i.e., ‘pw’ rather than ‘p’ then ‘w’ separately), it still would not provide enough information for the user to formulate a translation, as translations cannot not be formed on a word-by-word basis, with no grammatical context on the clause or phrase level. In other words, none of the four components of the *Fabricius Workbench* performed their function successfully nor in a way that improved or complemented the translation process for Hieroglyphic Egyptian texts.

One might ask whether this state of affairs is attributable to some kind of misunderstanding or misalignment of priorities. It is possible, for instance, that due to the involvement of multiple companies and institutions, the interests of the primary stakeholders affected the trajectory of the project’s development. Did Ubisoft’s intentions align with those of Google Arts and Culture, Psycle, or the academic institutes that contributed? I spoke directly to a representative from each of the key stakeholders to determine whether their interests conflicted at all and whether this affected the project itself, or its reception.

5.2 Interests of the Stakeholders

Ubisoft’s Director of Marketing, Pierre Miazga, stated that the company began work on the *Hieroglyphics Initiative* project after discussions with their consulting Egyptologists during the development of *Assassin’s Creed: Origins*. They wanted to ‘help out’ the academic community, which had been so instrumental in helping

Ubisoft produce such immersive video games with realistic historical settings. They wanted to do so by exploring ways they could demonstrate how new digital tools might be used in research. Their intention was to develop a digital toolkit for Egyptologists that could help their work with ancient translations to become easier and faster. Ubisoft's initial goal was thus to publish an open-source project that could be modified or adapted to the needs of researchers in the humanities. In Miazga's words, they wanted to 'be surprised by all the possible uses that could derive from [their] original publication'.[170]

Ubisoft's second goal was to demonstrate that a company that specialises in entertainment can contribute to science and research in 'their own humble way'. Although they no longer lead the development of *Fabricius*, Ubisoft still hope that the project will eventually have 'a positive impact on researchers' daily tasks'. In order to achieve either of these goals, however, Ubisoft needed to work alongside digital production company Psycle Interactive, who provided the technical know-how for developing the project.

At the commencement of the project, Psycle formulated three broad objectives, taking into account their lack of subject-matter knowledge and the academic landscape, as well as the limited data available for training a machine learning model.[171] Thus, their goals were to:

1. Explore ways in which machine learning could be applied to the translation of Hieroglyphic Egyptian
2. 'Give something back' to the academic community on Ubisoft's behalf
3. Publicly release whatever was produced for others to use and build upon

After consulting the academic community, Psycle realised that there would be more challenges than initially anticipated. To address this, a pipeline was formulated that outlined the steps involved in the process of translation:

1. Capture an inscription from its original source
2. Identify hieroglyphs

[170]Email from Pierre Miazga, Ubisoft, 30 November 2020.
[171]Email from Alex Fry, Psycle Interactive, 6 November 2020.

3. Sequence hieroglyphs
4. Parse sentence(s)
5. Produce translation

Psycle viewed each step as an opportunity for applying machine learning or other computing techniques. However, they recognised that significant progress would be unlikely to be made at any step of the process due to the lack of available training material. The end result was projected to not be significantly useful to the wider Egyptological community, nor a solid foundation to be built upon.

Psycle thus shifted their focus onto the workflow of the translation process itself. The goal was to identify and build a set of tools that would be accessible and able to be developed over time while also maintaining a consistent and coherent pipeline that supported end-to-end translation. Limited machine learning approaches were developed that could be applied to some of the steps outlined above, in a working proof-of-concept, aimed to demonstrate the overall principle, satisfying Psycle's first goal.

The web application that developed from these early steps in the process was the *Workbench*. The aim of the *Workbench* was to fulfil Ubisoft's initial goal, and the second of Psycle's initial goals – to provide a set of digital tools that can be used by the academic community. The *Workbench* was later joined by the *Learn* and *Play* modes and all three elements were launched as part of *Fabricius* in July 2020 by Google Arts and Culture. As such, Psycle's third goal was achieved through the launch of an open-source web application, upon which they and others can build and improve.

Lama El Desouky, Preservation Coordinator at Google Arts and Culture, stated that 'the project sought to identify whether machine learning could transform the process of collating, cataloguing, and understanding the written language of the pharaohs'.[172] Google wanted to demonstrate the utility of their *Cloud AutoML* service and produce an open-source program that made ancient Egyptian hieroglyphs accessible to anyone with internet access.[173] While the result of Google, Ubisoft, and Psycle's collaboration took the form of the *Fabricius*

[172] Email from Lama El Desouky, GAC, 11 December 2020.
[173] Coughenour 2020.

Workbench, which is open-source and may facilitate a wider audience having access to a program that explores Egyptian hieroglyphs, the outcomes of the case study conducted during this thesis suggest that the impact of this program on the Egyptological community has not been significant thus far. With more robust training, the *Cloud AutoML* service to which Google has provided Psycle access has the potential to support a more accurate machine learning tool for the auto-classification of hieroglyphs.

As the team responsible for co-developing the largest corpus of Ancient Egyptian words and texts worldwide, the project members of the *Thesaurus Linguae Aegyptiae* at the Berlin-Brandenburg Academy of Sciences and Humanities (BBAW) were engaged by Ubisoft and Google to provide large datasets for training the machine learning model.[174] The Academy project team was able to share their data under their open data policy.[175] The Academy project team was interested in how the program could identify scanned copies of Hieroglyphic texts and whether it would be possible to digitally encode hieroglyphic data using Optical Character Recognition, something already possible for texts written in alphabetical scripts, like Coptic.[176] The contribution of the BBAW to the *Fabricius* project was invaluable and their optimism for future projects that build upon the current program is indicative of the willingness for Egyptologists to continue developing digital programs to enhance research practices.

Macquarie University became involved in the development of *Fabricius* in response to Ubisoft, Psycle, and Google's call for academics to consult. As mentioned in Chapter 1, Alex Woods viewed the program as a potential framework for developing future digital assets for Egyptology, such as teaching programs, programs designed for marking up hieroglyphic data in a digital format, or some other form of digital tool for Egyptological research.

To sum up, it seems that Psycle's interests reflected Ubisoft's, as it was their job to produce the product that Ubisoft had in mind, and while Google provided the second round of funding, the overall goal remained the same: to produce a digital tool that would be useful to Egyptological research. By hosting the program

[174] Berlin-Brandenburgischen | Akademie der Wissenschaften 2021.
[175] All *TLA* project material is covered by a CC BY-SA 4.0 license, see **Berlin-Brandenburgischen | Akademie der Wissenschaften | Open Science and Research Data Management**.
[176] Email from Simon Schweitzer, BBAW, 25 February 2021.

on their Google Arts and Culture page, they ensure that it is accessible and in close proximity to related resources, such as Macquarie University's own Google Arts and Culture page, and other similar sites concerned with the humanities. As a result of the general consensus that the goal of the project was to produce an open-source web-based program that could inspire the development of future digital research tools for Egyptology, the interests of the stakeholders aligned well enough to carry the project to completion. As the *Fabricius Workbench* is not currently useful to the Egyptological community, it is possible that not enough discussion around the problems Egyptologists face and the appropriateness of the proposed solutions occurred between the academic stakeholders and the companies developing the technology.

Despite this, it helps further the conversation about the need to integrate more digital tools into research over time, as this can encourage researchers to ensure that Egyptological data is FAIR.[177] By way of summation, the SWOT analysis below will analyse the internal and external factors that could affect the future development of digital translation tools for Hieroglyphic Egyptian based on the *Fabricius Workbench.*

5.3 SWOT Analysis

Based on my own experience as an Egyptologist, my observations of the challenges experienced by the case study participants, and my familiarity with the program, I evaluated the strengths, weaknesses, opportunities, and threats of the *Fabricius Workbench*, discussed below. As I created the tutorial for the *Workbench* and corresponded directly with the stakeholders and developers of the program throughout the course of this thesis, I am ideally placed to conduct this analysis at this time and to propose developments for the future.

5.3.1 Strengths

The aspects of the *Workbench* that showed the most promise were more conceptual than practical. The participants identified the 'self-containment' aspect as the

[177] ANDS 2021.

most positive. The fact that the drawing of the facsimile, classification and sequencing of the hieroglyphs, and transliteration and translation are all contained within a single program was appealing to them. Although, it is important to note that while Egyptological epigraphers can usually translate Hieroglyphic Egyptian texts, not all Egyptologists who can translate Hieroglyphic Egyptian texts are epigraphers. Thus, while combining epigraphy and translation into one process sounds ideal in theory, it is neither necessary nor practical for the Egyptological community, unless the tool improved to a point where all Egyptological students were trained to do both using the *Workbench*, which is unlikely.

The 'self-containment' of the *Translation* panel was also identified as a useful design choice. Being able to input transliteration, translation, and interpretation within the one panel keeps the workspace tidy and being able to access the translation suggestions of the *Auto translate* function directly below the interpretation field reduces the need to switch between tabs, windows, programs, or mediums.

One of the most significant aspects of the *Workbench* is its ability to capture hieroglyphic data and encode it in a way that allows the computer to interact with it. With the project files being stored in the YAML format, there is a clear attempt to minimise the amount of data loss that can occur when encoding something as complex as hieroglyphic data. The program stores information about the co-ordinates of the hieroglyphs, how they relate to the original source image, and records the Gardiner Signs of each classified hieroglyph, as well as the percentages of the top three predictions, and their position within the sequence. Despite these strengths, the *Workbench* suffered from a multitude of weaknesses.

5.3.2 Weaknesses

This section is concerned only with the technical weaknesses of the tool, whereas I will explore the broader challenges the *Workbench* faced and the implications of these challenges in § 5.4.1.

The most prominent weaknesses of the *Workbench* were its significant lag, inaccurate auto-classification of hieroglyphs, and the design of the program's interface. For the lag to be addressed, all aspects of the program would need to be re-factored. The *Auto classify* function accesses a machine learning model for its classification process. The machine learning model would need to be re-trained with a much larger set of hieroglyphs and re-tested before employment. An accuracy rate of higher than 90% would be ideal, otherwise, the amount of time spent on correcting mis-classified hieroglyphs would add more time to the translation process. Most of the case study participants found that the interface of the *Workbench* was not substantially self-explanatory and would not have been able to navigate the program without first watching the tutorial, nor without prompting from an experienced user.

The drawing aspect of the *Workbench* suffered from not being sufficiently customisable, as it only offered two tools – *Draw* and *Erase* – and the only modifiable aspect was the width adjustment function. The width adjustment function provides a width measurement from one to 26, but the user does not know what this measurement means, other than the relative size of the *Draw*/*Erase* tool determined through trial and error. The user cannot choose the weight of the draw tool and the delay between the user's input and the output appearing on the screen was unmanageable, as the user could not see what they were drawing or erasing in real time.

5.3.3 Opportunities

The fact that Google Arts and Culture state that they intend to expand the current iteration of the *Workbench* into a larger scale project that will allow users to upload and translate images of different ancient texts other than Hieroglyphic Egyptian indicates that they are invested in the future of such digital tools for researchers, especially those concerned with ancient languages. As such, it is possible that Google Arts and Culture would also support the development of smaller scale individual projects that focus on specific aspects of the translation of Hieroglyphic Egyptian texts.

As access to ancient Egyptian monuments is dependent on travel circumstances and preservation status, being able to engage with wall scenes and texts remotely is proving to be crucial. With the preservation status of these monuments continuing to be threatened by urban expansion and environmental factors, traditional documentation methodologies, which are deeply human processes, need to be modified. Utilising digital tools that enable hieroglyphic data to be encoded and studied remotely would benefit the Egyptological community worldwide and encourage the use of FAIR data.

From my discussions with academic staff of the Department of History and Archaeology at Macquarie University, it is evident there is some interest in the field for the development of digital tools for Egyptology. As Macquarie University has established a connection with Google Arts and Culture and Psycle, it would be advantageous to continue the conversation this thesis has started in collaboration with the requisite companies in order to make these future digital tools for Egyptology a reality.

5.3.4 Threats

One of the biggest challenges every innovation must overcome is adoption. As discussed in § 3.1.2, innovations have to 'cross the chasm' in order to successfully be adopted by the wider market. As the *Workbench* does not represent a program that Egyptologists can utilise in its current state, widespread adoption at this stage would be difficult. The *Workbench* is, however, more of a collection of digital tools or components with the *potential* to be improved.

Future projects built on components of the *Workbench* would require funding, extensive amounts of time investment, and the knowledge and skills of experts in the field to develop. It is possible that initial investors will lose interest when the projects pass the prototype phase, or not enough interest will be garnered from Egyptologists to become involved in the collection and annotation of the necessary data. As such, those researchers and educators more inclined towards digital technologies and who are already adapting to the digital delivery of material due to the COVID-pivot would be the ideal innovators and early adopters of any digital tools that could develop out of the *Fabricius Workbench* project.[178] However, even with the time and efforts of these innovators and early adopters, such projects often experience difficulty succeeding. The post-prototype stage is where many unforeseen challenges arise, and maintenance and troubleshooting is

[178] The first two categories of the adoption curve, the innovators, and early adopters, need to be risk-takers ('attracted to high-risk/high-reward'), ambitious, and want to 'be trend setters' and 'role models' to their peers (Kaminski 2011, 3).

necessary. Often, there are no technologists available and thus, as the Egyptological community is a relatively small market, projects struggle to develop past this stage.

As machine learning models need clear examples (and copious amounts) of annotated hieroglyphs in order to learn how to correctly classify them, the fact that Egyptologists may not be able to supply enough images that are of sufficiently high quality is another possible obstacle. Clear communication between the technical developers (potentially Psycle) and Egyptological experts (ideally Egyptologists with Information Technology expertise, such as Nederhof and Rosmorduc) is therefore paramount for the projects discussed here to move forward and establish a community of early users who can demonstrate academic outcomes.

5.4 Outlook

The next step in developing on any of the components of the *Fabricius Workbench* is to formalise the data format of the program. This means producing a document written in the same computer language as the data object. The data object is the file that contains all of the information required to display the content in the program. Formalising and publishing the data format means that it is standardised and made available for others to build upon. Not all data in the current data file are relevant, so it needs to be edited and refined. The data object is currently stored as a YAML file, however, YAML is just a type of format and the data object can be stored as other types of formats, such as JSON or XML. The important aspect of the data object is that it can be read and interacted with by a computer.

The emphasis on data reusability and interoperability throughout the development of the *Fabricius Workbench* is the aspect of the project that responds to the question:

Are there aspects of the Fabricius Workbench that can be extracted, isolated and/or expanded upon as separate tools or projects that would be useful for collaboration among Egyptologists worldwide?

This focus on encouraging Egyptologists to collaborate using file types that ensure machine readability and data portability, highlights the importance of encoding hieroglyphic data in a digital (and thus shareable) format.

5.4.1 Improving Components of the *Fabricius Workbench*

The following section addresses the second research question posed in Chapter 1:

Are there improvements that can be made to the Fabricius Workbench that will make it more useful in translating Hieroglyphic Egyptian?

As the *Fabricius Workbench* cannot be effectively improved by viewing it as a complete program in its current iteration, we must focus on the four components that have been designed to interact with each other, and consider what improvements might be made to those, with a view that each component can be a stand-alone project with the capability of being integrated with other projects at a later date. This addresses the follow-up question:

Are there aspects of the Fabricius Workbench that can be extracted, isolated and/or expanded upon as separate tools or projects that would be useful in translating Hieroglyphic Egyptian?

Potential improvements to the four components of the *Workbench* are outlined below.

It is suggested that to improve the facsimile layer creation process of the *Workbench*, having the program interact directly with the image uploaded by the user would be more beneficial that requiring them to create a facsimile layer. The user would need to make small adjustments to the image, so some level of drawing tool would be required, however, it would be much faster and simpler for the user to fix hieroglyphs individually rather than editing an entire layer.

The sequencing process cannot be automated, as a computer cannot be taught to interpret the patterns and groupings of hieroglyphs; this requires intimate knowledge of the complexity and nuances of the orthography and grammar of Hieroglyphic Egyptian. However, the interface of this component of the *Workbench* can be improved. Rather than needing to manually select each *Sentence* and *Word* to which they want to assign hieroglyphs, the user could interact with the *Sequence* panel and the classified hieroglyphs, perhaps by selecting the desired *Word* in the *Sequence* panel, and while holding CNTRL, selecting the wanted/unwanted hieroglyph(s). Hieroglyphs could then easily be added to or removed from *Words*, and perhaps the *Sequence* panel could be improved by allowing *Words* to be dragged from one *Sentence* to another. This would make the process of assigning hieroglyphs to the correct *Words* and *Sentences* more intuitive and would make fixing mistakes like mis-assigned hieroglyphs less tedious than the current method, which requires the user to select the hieroglyph in the *Sequence* panel, delete it, then re-select it on the facsimile layer while ensuring the correct *Word* and *Sentence* is highlighted. The difference between 'selected' and 'deselected' *Words* and *Sentences* in the *Sequence* panel is the colour of the title bar: light grey means 'deselected', and slightly darker grey means 'selected'. This is understandably ambiguous for the user to interpret.

The *Auto classify* function was the only component that involved machine learning and proved unsuccessful. With such a low accuracy rate, the *Auto classify* function made the translation process take more rather than less time. Additionally, identifying hieroglyphs using personal experience and knowledge is an essential skill for all Egyptologists working with Hieroglyphic Egyptian texts. As such, having the computer identify the hieroglyphs for them is not necessary and would potentially erode vital skills.

A way in which this component could be useful is to speed up the process of marking up hieroglyphic information. If the *Workbench* could correctly identify the hieroglyphs represented in a text and record their classification, image co-ordinates, and spatial relationship with the hieroglyphs around them, it could be used to capture and store hieroglyphic data with which a computer can interact, Concrete outcomes of this interaction could be, for instance, that the information contained within the project file could be analysed for recurring hieroglyphic signs, patterns, or unusual groupings, as long as the classified hieroglyphs have been correctly grouped and labelled by the Egyptologist.

For this to be possible, however, the *Auto classify* function would need to be trained using large data sets of hieroglyphs sourced from original photos, with varying light conditions and angles, and Egyptological facsimiles. This is important, as it ensures that even during the training process, the resources used relate directly to the source monument. To achieve this, a broad annotation effort from Egyptologists (and potentially trained laypeople) around the world would be necessary, as the process of training machine learning models to recognise visual information is a long, multi-stage process that requires expert knowledge.[179] Such an effort would, however, encourage the spirit of collaboration.

The *Auto translate* function has a misleading title. This component of the *Fabricius Workbench* does not automatically translate the text, as the title implies. The function provides suggestions for individual hieroglyphs, and occasionally hieroglyph groupings, but the case study participants did not find its suggestions helpful. If the *Auto translate* function could access all open-source online databases, dictionaries, and corpora, rather than just a word list composed using data from the *TLA*, it could offer users a far more comprehensive pool of resources. The ability to search words in either English or using transliteration would also be a useful addition, as would including a more user-friendly interface that allows access to the grammatical information and context provided in the resources used. This would add to the self-containment aspect of the *Workbench* that the case study participants found appealing. With more resources and improved performance, projects based on any of the *Workbench* components discussed above could eventually support other ancient languages, as proposed by Google Arts and Culture. Such projects would require extensive user acceptance testing prior to release to the public.

5.4.2 Developing a Digital Pedagogical Tool

Developing a digital tool within in a pedagogical program would encourage an emerging generation of researchers to establish digital skills and techniques during their studies. Students can help the development and improvement of Egyptological digital tools by investing the time required to annotate training data sets, ensure the computer is classifying hieroglyphs correctly, and so on, while learning how to use the technology first-hand. Using such a tool would encourage students to learn how to encode hieroglyphic data using Unicode and prepare digital data for the Egyptological community. It would also instil the importance

[179] Clausner, Antonacopoulos and Plestchacher 2020, 73.

of the universality and transferability of data from an early stage in their career.

5.4.3 The Importance of Encoding Hieroglyphic Data

As discussed in § 2.2.1, to ensure cohesive collaboration among member of the Egyptological community it is imperative to establish a universal standard of encoding hieroglyphic data that enables digital analysis and transferability between both people and programs.[180]

Unicode is one method of achieving this universality, but it does have its limitations regarding its implementation within Egyptology.[181] For example, certain details of the appearance of hieroglyphs and the manipulation of the scale and position of hieroglyphs in relation to each other are difficult to encode, which impacts palaeographic studies of the material; however, Unicode's employment in the encoding of hieroglyphic data still has undeniable potential benefits. Nederhof, Polis, and Rosmorduc state that the 'aim of Unicode...is the interchange of encodings without introducing ambiguity', and that 'encodings can be effectively searched for patterns of signs and specific spatial arrangements'.[182] It is therefore worth considering whether identifying hieroglyphs by their Gardiner Code should be replaced with identifying them by their Unicode code point, as this would be universal across platforms. Avoiding ambiguity and supporting FAIR data principles are paramount to research integrity and data longevity.

As it currently stands, hieroglyphic texts and information regarding them are communicated between colleagues through the use of word processors, such as *Microsoft Word*. As there is no uniform or official system of encoding hieroglyphs yet, this requires the use of such tools as *JSesh* to include hieroglyphs in these documents, usually as images.[183] Even *JSesh* employs the MdC but not the RES, proposed by Rosmorduc (who created *JSesh*) in 2002.[184] Although *JSesh* is compatible with other hieroglyphic programs including *WinGlyph* and *TkSesh*, Rosmorduc states that the MdC is 'a bit outdated' and that future developments

[180] Nederhof, Polis and Rosmorduc 2021, 3; Bigelow and Holmes 1993, 291–292.
[181] Nederhof, Polis and Rosmorduc 2021, 3, 6-7.
[182] Nederhof, Polis and Rosmorduc 2021, 4, 6.
[183] Nederhof, Polis and Rosmorduc 2021, 2.
[184] Rosmorduc 2017.

for *JSesh* are in progress.[185] In order to establish a universal standard of encoding for the capture, analysis and sharing of hieroglyphic data, the Egyptological community needs to further the conversation on common goals, means of contributing, and the universal benefits to be gained from a deliberate and planned move towards more integration of digital technologies into teaching and research.

5.5 Conclusion

As demonstrated by the results of the case study, the *Fabricius Workbench* was not in itself a useful digital tool for Egyptologists translating Egyptian Hieroglyphic texts. Viewing the program as a collection of smaller purpose-built components that can help with various aspects of translation results allows these components to be analysed individually for their potential value. After applying SWOT analysis to the components of the *Workbench*, it is evident that while all of them suffer from sub-optimal performance, there is the potential for any one of them to be developed upon in the future. The various stakeholders of the *Fabricius Worbench* project each brought their own ideals and expectations to the process, and the published program, while not yet applicable in the field, did satisfy at least the preliminary goals of all of the stakeholders. That is to say, the idea of machine learning applied to research was investigated and a basis for future digital tools intended for the translation of ancient languages was developed. Projects inspired by or built upon the code and program designs of the components of the *Fabricius Workbench*, including teaching programs, may develop in the coming years, and provide the Egyptological community with a means of encoding their hieroglyphic data.

[185] Rosmorduc 2017.

Chapter 6

Conclusion

while this thesis started out with the aim of evaluating how useful the *Fabricius Workbench* program could be in the translation of Hieroglyphic Egyptian texts, it became evident that it needed to do more than just evaluate one program designed to support end-to-end translation. Had the program proved successful, the next steps would involve focusing on the marketing and adoption of the program on a larger scale. However, since the program proved unsuccessful, a decision needed to be made about whether to accept it as a failed endeavour, or to either completely start over, or build on what had already been made. As the *Fabricius Workbench* represented an attempt to contribute to the conversation on how digital tools can be utilised to support the generation and annotation of textual corpora, the focus of the thesis shifted to engage with this conversation more actively.

To this end, rather than viewing the *Workbench* as a single program, it was viewed as a collection of tools, or components, which interacted with each other in order to support the process of translation. As such, each component represented an opportunity to build on what had already been developed, but on a smaller scale. while the *Workbench* did not prove successful at supporting end-to-end translation in its current state, it would be a missed opportunity to dismiss it as a failed attempt. It would also be far too time-consuming and pointless to try and create a completely new program, as the data format of the *Workbench* provides a useful framework for developing digital tools based on each of the four components of the *Workbench*. Further to this, it became evident that any projects that eventuate from this thesis would need to focus on the importance of encoding hieroglyphic data in a way that is FAIR. Specifically, encoding hieroglyphic data into a computer makes it machine legible and requires a standard system of encoding to be implemented to ensure that it can be shared easily without data loss.

Egyptologists have been engaging with digital technologies in their research in various ways for decades. With the Covid-pivot phenomenon impacting the delivery of teaching content and exchange of data for the purpose of collaboration in a likely permanent way, the continued integration of digital technologies into research and education has undeniable benefits. Analysing large corpora of texts currently requires extensive time and effort to be invested. As computers can store and apply analyses to large amounts of data faster than humans, digitally encoded text and sign corpora could be searched, compared, and analysed in a shorter amount of time.

The *Fabricius Workbench* does not currently facilitate all of the benefits mentioned above. Each of the components of the *Workbench* experienced difficulties, including errors, lag, and low rates of accuracy. Despite this, by building on what has already been created, it might be possible to develop smaller-scale projects that will support the digital encoding of hieroglyphic data. As part of this endeavour, it would also be worth developing teaching tools that can help students of Hieroglyphic Egyptian learn vital skills in encoding, including how to use code points for Unicode hieroglyphic characters and control characters, how to search and analyse encoded data, and how to mark up and label images.

As the Covid-pivot has necessitated an emphasis on online learning for students, it would be advantageous to focus on improving digital teaching tools that support remote education. Introducing more digital tools during the learning stage of the process would also allow students to take their newly acquired digital skills into later education or research. It would also mean that these products would not have to appeal directly to career researchers, but to teachers and students.

The primary outcome of this thesis a contribution to the conversation about the need for Egyptologists to collaborate and share data in a way that encourages maximising what can be done with the information researchers gather and ensures that data uphold the FAIR principles. The *Fabricius Workbench* is thus an example of an attempt to create a digital toolkit for Egyptologists interested in translating Hieroglyphic Egyptian texts, and this thesis has demonstrated that while it was not a successful attempt, it can act as the first stepping-stone towards the greater adoption of digital encoding for hieroglyphic data.

Appendices

Appendix A

Ethics Approval for Case Study

Arts Subcommittee
Macquarie University, North Ryde
NSW 2109, Australia

07/07/2020

Dear Associate Professor Ross,

Reference No: 17497
Project ID: 6791
Title: Innovations in Machine Learning

Thank you for submitting the above application for ethical review. The Arts Subcommittee has considered your application.

I am pleased to advise that ethical approval has been granted for this project to be conducted by Associate Professor Shawn Ross, and other personnel: Dr Alexandra Woods, Dr Brian Ballsun-Stanton, Miss Bree Kelly.

This research meets the requirements set out in the *National Statement on Ethical Conduct in Human Research 2007, (updated July 2018)*.

Conditions of approval:

When communicating with participants, please be sure to explain to them that their data will be 'deidentified' via participant number in coding data and publications, rather than 'anonymised'.

Standard Conditions of Approval

1. Continuing compliance with the requirements of the *National Statement,* available at the following website: https://nhmrc.gov.au/about-us/publications/national-statement-ethical-conduct-human-research-2007-updated-2018.

2. This approval is valid for five (5) years, subject to the submission of annual reports. Please submit your reports on the anniversary of the approval for this protocol. You will be sent an automatic reminder email one week from the due date to remind you of your reporting responsibilities.

3. All adverse events, including unforeseen events, which might affect the continued ethical acceptability of the project, must be reported to the subcommittee within 72 hours.

4. All proposed changes to the project and associated documents must be submitted to the subcommittee for review and approval before implementation. Changes can be made via the Human Research Ethics Management System.

The HREC Terms of Reference and Standard Operating Procedures are available from the Research Services website: https://www.mq.edu.au/research/ethics-integrity-and-policies/ethics/human-ethics.

It is the responsibility of the Chief Investigator to retain a copy of all documentation related to this project and to forward a copy of this approval letter to all personnel listed on the project.

Should you have any queries regarding your project, please contact the Faculty Ethics Officer.

The Arts Subcommittee wishes you every success in your research.

Yours sincerely,

Dr Mianna Lotz

Chair, Arts Subcommittee

The Faculty Ethics Subcommittees at Macquarie University operate in accordance with the National Statement on Ethical Conduct in Human Research 2007, (updated July 2018), [Section 5.2.22].

References

Abt, Jeffrey (1998). 'Drawing over Photographs: James H. Breasted and the Scientizing of Egyptian Epigraphy, 1895–1928'. In: 14.1, pp. 19–69. DOI: 10.1080/01973762.1998.9658439. URL: https://web.archive.org/web/20210319062117/https://www.tandfonline.com/doi/abs/10.1080/01973762.1998.9658439.

Adkins, Lesley and Roy Adkins (2001). *The Keys to Egypt: The Race to Read the Hieroglyphs*. London: HarperCollins Publishers.

Allen, James P. (2010). *Middle Egyptian: An Introduction to the Language and Culture of Hieroglyphs*. Second Edition, Revised. Cambridge: Cambridge University Press.

— (2013). *The Ancient Egyptian Language: An Historical Study*. Cambridge: Cambridge University Press.

Anderson, Valerie (2020). 'A Digital Pedagogy Pivot: Re-Thinking Higher Education Practice from an HRD Perspective'. In: *Human Resource Development International* 23.4, pp. 452–467. DOI: 10.1080/13678868.2020.1778999.

ANDS (2021). *The FAIR Data Principles*. URL: https://web.archive.org/web/20210319062202/https://www.ands.org.au/working-with-data/fairdata (visited on 21/03/2021).

ASCII (2021). *ASCII Table and Description*. URL: https://web.archive.org/web/20210319061347/https://www.asciitable.com/ (visited on 21/03/2021).

Assael, Yannis, Thea Sommerschield and Jonathon Prag (2019). 'Restoring Ancient Text Using Deep Learning: A Case Study on Greek Epigraphy'. In: *Proceedings of the 2019 Conference on Empirical Methods in Natural Language Processing and the 9th International Joint Conference on Natural Language Processing (EMNLP-IJCNLP)*, pp. 6368–6385.

BBAW - Ancient Egyptian Dictionary Project (2021). *The Thesaurus Linguae Aegyptiae on the Internet*. URL: https://web.archive.org/web/20210223171001/https://aaew.bbaw.de/tla/index.html (visited on 21/03/2021).

Berlin-Brandenburgischen | Akademie der Wissenschaften (2021). *Startseite Berlin-Brandenburgische Akademie der Wissenschaften – Berlin-Brandenburgische Akademie der Wissenschaften*. URL: https://web.archive.org/web/20210319044805/https://www.bbaw.de/ (visited on 21/03/2021).

Berti, Monica and Franziska Naether (2015). *Minutes of the Final Discussion of "DHEgypt15"*.

Bevan, Nigel (2009). 'What Is the Difference Between the Purpose of Usability and User Experience Evaluation Methods?' In: *Proceedings of the Workshop UXEM'09 (INTERACT'09)* 9. URL: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.460.6252&rep=rep1&type=pdf.

Bierbrier, Morris L., ed. (2019). *Who Was Who in Egyptology*. Fifth Edition. London: Egypt Exploration Society.

Bigelow, Charles and Kris Holmes (1993). 'The Design of a Unicode Font'. In: *Electronic Publishing* 6.3, pp. 289–305.

Burnard, Lou (2014). *What Is the Text Encoding Initiative? How to Add Intelligent Markup to Digital Resources*. Encyclopédie Numérique. Marseille: OpenEdition Press. ISBN: 978-2-8218-3459-0. URL: https://web.archive.org/web/20210319062323/https://books.openedition.org/oep/426.

Caminos, Ricado and Henry Fischer (1976). *Ancient Egyptian Epigraphy and Palaeography: The Recording of Inscriptions and Scenes in Tombs and Temples by Ricardo Caminos and Archaeological Aspects of Epigraphy and Palaeography by Henry Fischer*. New York: Metropolitan Museum of Art.

Chenhall, Robert G. (Sept. 1968). 'The Impact of Computers on Archaeological Theory: An Appraisal and Projection'. In: *Computers and the Humanities: Annual Survey of Recent Developments* 3.1, pp. 15–24. URL: https://web.archive.org/web/20210319062432/https://www.jstor.org/stable/30203971.

Clausner, Christian, Apostolos Antonacopoulos and Stefan Plestchacher (2020). 'Efficient and Effective OCR Engine Training'. In: *International Journal on Document Analysis and Recognition (IJDAR)* 23, pp. 73–88. DOI: 10.1007/s10032-019-00347-8.

Coughenour, Chance (2020). *Unravel the Symbols of Ancient Egypt*. URL: https://web.archive.org/web/20210319044212/https://blog.google/outreach-initiatives/arts-culture/unravel-symbols-ancient-egypt/ (visited on 21/03/2021).

de Vries, Erik, Martijn Schoonvelde and Gijs Schumacher (2018). ‘No Longer Lost in Translation: Evidence That Google Translate Works for Comparative Bag-of-Works Text Application’. In: *Political Analysis* 26.4, pp. 417–430. DOI: 10.1017/pan.2018.26.

Der Manuelian, Peter (1988). ‘Proglyph: Hieroglyphic Font for the Apple Macintosh’. In: *Journal of the American Research Center in Egypt* 25, pp. 237–241. URL: https://web.archive.org/web/20210319062458/https://www.jstor.org/stable/40000882.

— (1998). ‘Digital Epigraphy: An Approach to Streamlining Egyptological Epigraphic Method’. English. In: *Journal of the American Research Center in Egypt* 35, pp. 97–113.

Donker van Heel, Koen *et al.* (2018). *Introduction*. URL: https://web.archive.org/web/20210319062544/https://dmd.wepwawet.nl/ (visited on 21/03/2021).

Dorst, Kees (2011). ‘The Core of ‘Design Thinking’ and Its Application’. In: *Design Studies* 32.6, pp. 521–532. DOI: 10.1016/j.destud.2011.07.006.

Dreyer, Günter (1998). *Umm el-Qaab*. Archäologische Veröffentlichungen (Deutsches Archäologisches Institut. Abteilung Kairo). Mainz: Verlag Philipp von Zabern.

El Daly, Okasha (2005). *Egyptology: The Missing Millennium: Ancient Egypt in Medieval Arabic Writing*. London: UCL Press.

Erman, Adolf and Hermann Grapow, eds. (1926–1931). *Wörterbuch der ägyptischen Sprache*. German. Berlin: Akademie-Verlag.

Evans, Linda and Anna-Latifa Mourad (2018). ‘DStretch® and Egyptian Tomb Paintings: A Case Study from Beni Hassan’. In: *Journal of Archaeological Science: Reports* 18, pp. 78–84. DOI: 10.1016/j.jasrep.2018.01.011.

Everson, Michael (2006). *Sources for the Encoding of Egyptian Hieroglyphs*. URL: http://std.dkuug.dk/jtc1/sc2/wg2/docs/n3182.pdf..

Everson, Michael and Bob Richmond (2008). *EGYPTOLOGICAL YOD and Cyrillic Breathings*. URL: http://std.dkuug.dk/jtc1/sc2/wg2/docs/n3382.pdf.

Faulkner, Raymond O. (1962). *A Concise Dictionary of Middle Egyptian*. Oxford: Griffith Institute.

Franke, Detlef (2001). *Middle Kingdom (c.2000 – 1650 BCE)*. In: ed. by Donald B. Redford. Vol. 2. 3 vols. Oxford: Oxford University Press, pp. 393–400. ISBN: 978-0-19-510234-5.

Gardiner, Sir Alan H. (1927). *Egyptian Grammar: Being an Introduction to the Study of Hieroglyphs*. English. Oxford: Clarendon Press.

Gardiner, Sir Alan H. (1957). *Egyptian Grammar: Being an Introduction to the Study of Hieroglyphs*. Third Edition. Oxford: Griffith Institute.

Ghazinoory, Sepehr, Mansoureh Abdi and Mandana Azedegan-Mehr (2011). 'SWOT Methodology: A State-of-the-Art Review for the Past, A Framework for the Future'. In: *Journal of Business Economics and Management* 12.1, pp. 24–48. DOI: 10.3846/16111699.2011.555358. URL: https://web.archive.org/web/20210319062717/https://journals.vgtu.lt/index.php/JBEM/article/view/4981.

Gohy, Stéphanie, Benjamin Martin Leon and Stéphane Polis (2013). 'Automated Text Categorization in a Dead Language: The Detection of Genres in Late Egyptian'. In: *Texts, Languages & Information Technology in Egyptology: Selected Papers from the Meeting of the Computer Working Group of the International Association of Egyptologists (Informatique & Égyptologie), Liège, 6-8 July 2010*. Ed. by Stéphane Polis and Jean Winand. Liège: Presses Universitaires de Liège, pp. 61–74.

Google (2021a). *DeepL Translate*. URL: https://web.archive.org/web/20210319062801/https://www.deepl.com/en/translator (visited on 21/03/2021).

— (2021b). *Google Translate*. URL: https://web.archive.org/web/20210319062228/https://translate.google.com/ (visited on 21/03/2021).

— (2021c). *M25 / Google Zoo*. URL: https://web.archive.org/web/20210320144243/https://m35.com.au/projects/google-zoo/ (visited on 21/03/2021).

Google Arts and Culture (2020a). *About the Project*. URL: https://artsexperiments.withgoogle.com/fabricius/en/about (visited on 21/03/2021).

— (2020b). *Play*. URL: https://artsexperiments.withgoogle.com/fabricius/en/play/translator (visited on 21/03/2021).

— (2020c). *What Is Fabricius?* URL: https://artsexperiments.withgoogle.com/fabricius/ (visited on 21/03/2021).

— (2020d). *Workbench*. URL: https://web.archive.org/web/20210319062844/https://fabriciusworkbench.withgoogle.com/ (visited on 21/03/2021).

Google Cloud (2018). *Google Cloud Next '18 London: Day 2 Keynote*. London. URL: https://web.archive.org/web/20210320130214if_/https://www.youtube.com/watch?v=nIq2pkNcfEI.

— (2019). *Ubisoft: Using Machine Learning to Transform Our Understanding of the Ancient World*. URL: https://web.archive.org/web/20210319063314/https://cloud.google.com/customers/ubisoft.

Gozzoli, Roberto G. (2013). ‘Hieroglyphic Text Processors, Manuel de Codage, Unicode, and Lexicography’. In: *Texts, Languages & Information Technology in Egyptology: Selected Papers from the Meeting of the Computer Working Group of the International Association of Egyptologists (Informatique & Égyptologie), Liège, 6-8 July 2010*. Ed. by Stéphane Polis and Jean Winand. Liège: Presses Universitaires de Liège, pp. 89–101.

Gracia Zamacona, Carlos (2013). ‘A Database for the Coffin Texts’. In: *Texts, Languages & Information Technology in Egyptology: Selected Papers from the Meeting of the Computer Working Group of the International Association of Egyptologists (Informatique & Égyptologie), Liège, 6-8 July 2010*. Ed. by Stéphane Polis and Jean Winand. Liège: Presses Universitaires de Liège, pp. 139–155.

Grayston, Justin (2021). *googleartsculture/workbench*. URL: https://web.archive.org/web/20210319052738/https://github.com/googleartsculture/workbench (visited on 21/03/2021).

Griffith Institute (2021). *Welcome to the Online Egyptological Bibliography (OEB)*. URL: https://web.archive.org/web/20210320130717/http://oeb.griffith.ox.ac.uk/ (visited on 21/03/2021).

Groves, Michael and Klaus Mundt (2014). ‘Friend or Foe? Google Translate in Language for Academic Purposes’. In: *English for Specific Purposes* 37, pp. 112–121. DOI: http://dx.doi.org/10.1016/j.esp.2014.09.001.

Guszcza, James, Peter Evans-Greenwood and Harvey Lewis (2017). ‘Cognitive Collaboration: Why Humans and Computers Think Better Together’. In: Deloitte Review 20, pp. 9–29.

Hannig, Rainer (2006). *GroSSes Handwörterbuch gyptisch-Deutsch (2800-950 v. Chr.)* Dermstadt: Phillip von Zabern.

Hao, Karen (2018). ‘What Is Machine Learning?’ In: *MIT Technology Review*. URL: https://web.archive.org/web/20210320131145/https://www.technologyreview.com/2018/11/17/103781/what-is-machine-learning-we-drew-you-another-flowchart/ (visited on 21/03/2021).

He, Kaiming *et al.* (2015). *Delving Deep into Rectifiers: Surpassing Human-Level Performance on ImageNet Classification*. URL: https://web.archive.org/web/20210304123636/https://arxiv.org/pdf/1502.01852v1.pdf.

Helms, Marilyn M. and Judy Nixon (2010). 'Exploring SWOT Analysis – Where Are We Now? A Review of Academic Research From the Last Decade'. In: *Journal of Strategy and Management* 3.3, pp. 215–251. DOI: 10.1108/17554251011064837.

Hölbl, Günther (2001). 'Ptolemaic Period'. Trans. by Elizabeth Schwaiger. In: The Oxford Encyclopedia of Ancient Egypt 3. Ed. by Donald B. Redford, pp. 75–85.

Holzhäuer, Eberhard (2021). *SESCH | Willkommen zur Ägyptologischen Datenbank AHA, Berlin*. URL: https://web.archive.org/web/20210319063557/http://www.sesch-projekt.de/webseite/index.php (visited on 21/03/2021).

Jegorović, Boris (2017). *A Concise Dictionary of Middle Egyptian by Raymond O. Faulkner Modernized by Boris Jegorović: Now with English-Egyptian Index and List of Rare Hieroglyphs*. Oxford: Griffith Institute.

Jones, Dilwyn (2000). *An Index of Ancient Egyptian Titles, Epithets and Phrase of the Old Kingdom*. Vol. 2. BAR International Series. Oxford: British Archaeological Reports Oxford Ltd.

Jushaninowa, Julia (2015). *Digital Humanities Enhanced. Challenges and Prospects of Ancient Studies. A Retrospect on the DH-Conference in November 2015 in Leipzig.*

Kaminski, June (2011). 'Diffusion of Innovation Theory'. In: *Canadian Journal of Nursing Informatics*. Theory in Nursing Informatics Column 9.2, pp. 1–7.

Kelly, Bree, Brian Ballsun-Stanton and Alexandra Woods (2020a). *Decoding Ancient Egyptian Hierolgyphs*. URL: https://artsandculture.google.com/story/3AWRthyomDRf2w (visited on 21/03/2021).

— (2020b). *Explore The Fabricius Workbench*. URL: https://web.archive.org/web/20210319063817/https://artsandculture.google.com/story/explore-the-fabricius-workbench/gwXxcXwClTM8JA (visited on 21/03/2021).

Kelly, Bree, Linda Evans and Brian Ballsun-Stanton (2020). *Technology and Egyptology*. URL: https://artsandculture.google.com/story/kQVB7V2qDsHG7Q (visited on 21/03/2021).

Kilani, Marwan *et al.* (2021). *SINUHE THE HIEROTYPER*. URL: http://somiyagawa.github.io/SINUHE-the-Hierotyper/ (visited on 21/03/2021).

Król, Karol and Dariusz Zdonek (2019). 'Peculiarity of the Bit Rot and Link Rot Phenomena'. In: *Global Knowledge, Memory and Communication* 69.1/2, pp. 20–37.

Lewis, Clayton *et al.* (1990). 'Testing a Walkthrough Methodology for Theory-Based Design of Walk-up-and-Use Interfaces'. English. In: *CHI '90: Proceedings of the*

SIGCHI Conference on Human Factors in Computing Systems, pp. 235–242. DOI: 10.1145/97243.97279.

Lichtheim, Miriam, ed. (2006). *Ancient Egyptian Literature, Volume I: The Old and Middle Kingdoms*. Berkeley: University of California Press.

Licklider, J C R (1960). 'Man-Computer Symbiosis'. In: *IRE Transactions on Human Factors in Electronics* HFE-1, pp. 4–11.

Loprieno, Antonio (1995). *Ancient Egyptian: A Linguistic Introduction*. Cambridge: Cambridge University Press.

Macketanz, Vivien, Aljoscha Burchardt and Hans Uszkoreit (2018). *TQ-AutoTest: Novel Analytical Quality Measure Confirms That DeepL Is Better Than Google Translate*. Tech. rep. The Globalization and Localization Association (GALA). URL: https://www.dfki.de/fileadmin/user_upload/import/10174_TQ-AutoTest_Novel_analytical_quality_measure_confirms_that_DeepL_is_better_than_Google_Translate.pdf.

Mansour, Ahmed and Azza Ezzat (2015). 'The Role of E-Learning in Egyptology: 'Hieroglyphs: Step-by-Step' Website as a Case Study'. English. In: *International Congress of Egyptologists* XI, pp. 362–367.

Mantovan, Lorenzo and Loris Nanni (2020). 'The Computerization of Archaeology: Survery on AI Techniques'. In: *SN Computer Science* 1.267, pp. 1–47.

Migawa, So (2020). *somiyagawa / SINUHE-the-Hierotyper*. URL: https://web.archive.org/web/20210321025727/https://github.com/somiyagawa/SINUHE-the-Hierotyper (visited on 21/03/2021).

Moore, Geoffrey A. (2014). *Crossing the Chasm: Marketing and Selling High-Tech Products to Mainstream Customers*. Third Edition. Harper Business.

Museum Tours (2021). *About EZGlyph*. URL: http://www.ezglyph.com/home.htm (visited on 21/03/2021).

Nederhof, Mark-Jan (2002). 'A Revised Encoding Scheme for Hieroglyphic'. In: *Proceedings of the XIV Computer-aided Egyptology Round Table*, pp. 1–12.

— (2013a). 'Flexible Use of Text Annotations and Distance Learning'. In: *Texts, Languages & Information Technology in Egyptology: Selected Papers from the Meeting of the Computer Working Group of the International Association of Egyptologists (Informatique & Égyptologie), Liège, 6-8 July 2010*. Ed. by Stéphane Polis and Jean Winand. Liège: Presses Universitaires de Liège, pp. 75–88.

Nederhof, Mark-Jan (2013b). 'The Manuel de Codage Encoding of Hieroglyphs Impedes Development of Corpora'. In: *Texts, Languages & Information Technology in Egyptology: Selected Papers from the Meeting of the Computer Working Group of the International Association of Egyptologists (Informatique & Égyptologie), Liège, 6-8 July 2010*. Ed. by Stéphane Polis and Jean Winand. Liège: Presses Universitaires de Liège, pp. 103–110.

— (2016). 'OCR of Handwritten Transcriptions of Ancient Egyptian Hieroglyphic Text'. In: *Altertumswissenschaften in a Digital Age: Egyptology, Papyrology and Beyond: Proceedings of a Conference and Workshop in Leipzig, November 4-6, 2015*. Ed. by Monica Berti, Contribution 17. URL: https://nbn-resolving.org/urn:nbn:de:bsz:15-qucosa-201704.

Nederhof, Mark-Jan, Stéphane Polis and Serge Rosmorduc (2021). *Unicode Control Characters for Ancient Egyptian*.

Nederhof, Mark-Jan and Vinodh Rajan (18th Apr. 2016). *Comments on Three Control Characters for Egyptian Hieroglyphs*.

Nederhof, Mark-Jan, Vinodh Rajan, Johannes Lang *et al.* (2016a). *A Comprehensive System of Control Characters for Ancient Egyptian Hieroglyphic Text (Preliminary Version)*.

— (2016b). *A System of Control Characters for Ancient Egyptian Hieroglyphic Text*.

Never Sit Still (2020). *Google Zoo / Brand Motion System*. URL: https://web.archive.org/web/20200202111113/https://neversitstill.tv/projects/google-zoo-brand-motion-system/ (visited on 21/03/2021).

Nielson, Jakob (1998). *Fighting Linkrot*. URL: https://web.archive.org/web/20210319064006/https://www.nngroup.com/articles/fighting-linkrot/ (visited on 21/03/2021).

Norman, Donald (2013). *The Design of Everyday Things: Revised and Expanded Edition*. New York: Basic Books.

Ockinga, Boyo (2012). *A Concise Grammar of Middle Egyptian*. Dermstadt/Mainz: Phillip von Zabern.

Oxford English Dictionary (2020a). *"machine, n."* URL: https://www.oed.com/view/Entry/111850?rskey=bMUb6f&result=1&isAdvanced=false#eid38479194 (visited on 21/03/2021).

— (2020b). *"photogrammetry, n."* URL: https://www.oed.com/view/Entry/142817?redirectedFrom=photogrammetry (visited on 21/03/2021).

Panov, Maxim (2021). *Hieroglyphica*. URL: https://web.archive.org/web/20210316060149/http://hieroglyphica.com/ (visited on 21/03/2021).

Polis, Stéphane, Anne-Claude Honnay and Jean Winand (2013). 'Building an Annotated Corpus of Late Egyptian: The Ramses Project: Review and Perspectives'. In: *Texts, Languages & Information Technology in Egyptology: Selected Papers from the Meeting of the Computer Working Group of the International Association of Egyptologists (Informatique & Égyptologie), Liège, 6-8 July 2010*. Liège: Presses Universitaires de Liège, pp. 25–44.

Psycle Interactive (2020). *The Hieroglyphics Initiative - Breakout Session @ Google Next '18*. URL: https://web.archive.org/web/20210320135801if_/https://www.youtube.com/watch?v=2JjnshdXWqo (visited on 21/03/2021).

— (2021). *Psycle Interactive*. URL: https://web.archive.org/web/20210319064440/https://www.psycle.com/ (visited on 21/03/2021).

Regulski, Ilona (2016). 'The Origins and Early Development of Writing in Egypt'. In: *Oxford Handbooks Online*, pp. 1–28. DOI: 10.1093/oxfordhb/9780199935413.013.61.

Richmond, Bob (2015). *Proposal to Encode Three Control Characters for Eygptian Hierolglyphs*. Proposal L2/15-123.

Richmond, Bob and Andrew Glass (2016). *Proposal to Encode Three Control Characters for Eygptian Hieroglyphs*. Proposal L2/16-018R.

Ries, Eric (2011). *The Lean Startup: How Today's Entrepreneurs Use Continuous Innovation to Create Radically Successful Businesses*. London: Random House USA Inc.

Rogers, Everett M. (2003). *Diffusion of Innovations*. Fifth Edition. New York: Simon and Schuster.

Rosmorduc, Serge (2014). *JSesh*. URL: https://web.archive.org/web/20210319064613/https://jsesh.qenherkhopeshef.org/ (visited on 21/03/2021).

— (2017). *01. Introducción*. URL: https://web.archive.org/web/20210320141001/http://jseshdoc.qenherkhopeshef.org/doku.php/doc:es:documentation?s%5B%5D=manuel (visited on 21/03/2021).

— (2020a). 'Automated Transliteration of Late Egyptian Using Neural Networks: An Experiment in "Deep Learning"'. In: *Lingua Aegyptia - Journal of Egyptian Language Studies* 28, pp. 233–257. DOI: 10.37011/lingaeg.28.07. URL: https://web.archive.org/web/20210321030547/https://hal.archives-ouvertes.fr/hal-03118369.

Rosmorduc, Serge (2020b). *rosmord/mac_transliteration_keyboards*. URL: https://github.com/rosmord/mac_transliteratin_keyboards (visited on 21/03/2021).

— (2021). *TKSESH: A Hieroglyphic Database System*. URL: https://web.archive.org/web/20210319064744/http://tksesh.qenherkhopeshef.org/INWORK/IEXII/ (visited on 21/03/2021).

Rosmorduc, Serge, Stéphane Polis and Jean Winand (2009). 'Ramses: A New Research Tool in Philology and Linguistics'. In: *Information Technology and Egyptology in 2008. Proceedings of the Meeting of the Computer Working Group of the International Association of Egyptologists (Informatique et Egyptologie), Vienna, 8–11 July 2008*. Ed. by Nigel Strudwick. Bible in Technology 2. New Jersey: Georgia Press, pp. 133–142. URL: https://web.archive.org/web/20210319064535/https://orbi.uliege.be/handle/2268/26438.

Sadeh, Tamar (2008). 'User Experience in the Library: A Case Study'. In: *New Library World* 109.1/2, pp. 7–24. DOI: 10.1108/03074800810845976. URL: https://web.archive.org/web/20210319064803/https://www.emerald.com/insight/content/doi/10.1108/03074800810845976/full/html.

Samaan, Mariam *et al.* (2016). 'Close-Range Photogrammetric Tool for Epigraphic Surveys'. In: *ACM Journal on Computing and Cultural Heritage* 9.3, Article 6 (19 pages).

Strudwick, Nigel (1988). 'Proglyph - A Review'. In: *Informatique et Égyptologie* 6, pp. 7–10.

TEI (2021). *Text Endocing Initiative*. URL: https://web.archive.org/web/20210319064908/https://tei-c.org/ (visited on 21/03/2021).

The Deir el-Medina Database (2021). *Trlit_CG Times Font*. URL: https://web.archive.org/web/20210319062544/https://dmd.wepwawet.nl/%20fonts.htm (visited on 21/03/2021).

The Metropolitan Museum of Art (2021). *Stela of the Steward Mentuwoser | Middle Kingdom*. URL: https://web.archive.org/web/20210319063856/https://www.metmuseum.org/art/collection/search/544320 (visited on 21/03/2021).

The Oriential Institute of The Univeristy of Chicago (2021). *The Epigraphic Survey | The Oriental Institute of the University of Chicago*. URL: https://web.archive.org/web/20210319063738/https://oi.uchicago.edu/research/projects/epigraphic-survey (visited on 21/03/2021).

Unicode, Inc. (2021). *Egyptian Hieroglyphs | Range: 13000–1342F*. Tech. rep. URL: https://web.archive.org/web/20210302190413/http://www.unicode.org/charts/PDF/U13000.pdf.

Université de Liège (2021). *Ramses Online | An Annotated Corpus of Late Egyptian*. URL: http://ramses.ulg.ac.be/ (visited on 21/03/2021).

Urcia, Alberto *et al.* (2018). 'From Plastic Sheets to Tablet PCs: A Digital Epigraphic Method for Recording Egyptian Rock Art and Inscriptions'. In: *African Archaeological Review* 35, pp. 169–189. DOI: 10.1007/s10437-018-9297-z.

van de Beek, Nicky (2017). *Hetepherakhty*. URL: https://web.archive.org/web/20210319065011/https://nickyvandebeek.com/projects/hetepherakhty/ (visited on 07/03/2021).

Verner, Miroslav (2001). 'Old Kingdom'. In: *The Oxford Encyclopedia of Ancient Egypt* 2. Ed. by Donald B. Redford, pp. 585–591.

Vértes, Krisztián (2014). *Digital Epigraphy*. Second Edition. Chicago: Epigraphic Survey at the Oriental Institute of the University of Chicago. ISBN: 978-1-61491-021-3.

— (2021). *About Us*. URL: https://web.archive.org/web/20210319065037/https://www.digital-epigraphy.com/about-us (visited on 21/03/2021).

Weihrich, Heinz (1982). 'The TOWS Matrix - A Tool for Situational Analysis'. In: *Long Range Planning* 15.2, pp. 54–66.

World Economic Forum (2016). *The Future of Jobs: Employment, Skills and Workforce Strategy for the Fourth Industrial Revolution*. Tech. rep. URL: https://web.archive.org/web/20210319060357/https://web.archive.org/web/20210319060357/https://www3.weforum.org/docs/WEF_Future_of_Jobs.pdf.

YAML (2021). *YAML Ain't Markup Language*. URL: https://web.archive.org/web/20210318102345/https://yaml.org/ (visited on 21/03/2021).