

Engineering Historical Memory and the Interactive Exploration of Archival Documents: The Online Application for Pope Gregory X's Privilege for the Monastic Community of Mount Sinai (1274) as a Prototype

¹Andrea Nanetti, ²Davide Benvenuti

^{1,2}Nanyang Technological University, Singapore

¹andrea.nanetti@ntu.edu.sg

²dbenvenuti@ntu.edu.sg

Abstract

This paper presents the results of a research project in Digital Humanities. The project explores archival documents within the online system Engineering Historical Memory (EHM). EHM enables users to read primary historical sources according to different knowledge and expertise levels interactively. Here, as a showcase, the authors present the interdisciplinary research (Diplomatics, History, 3D Visualisation) that empowered the online publication of the original privilege issued by pope Gregory X to the monastic community of Mount Sinai in 1274. The application embodies the following research tools: 1) Digital recomposition and restoration of the photographic survey of the original parchment split into two pieces and held in two different locations in Egypt (Holy Monastery of St Catherine at Mt Sinai, and the Archive of the same monastery in Cairo); 2) Force-directed graph to navigate the diplomatics structure of the papal privilege; 3) Interactive geospatial visualisations of the place names (satellite views and political maps); 4) Search engines for scholarly texts, images, and videos related to the individual diplomatics, historical, and geographical entities itemised in the application; 5) 3D modelling of the lost lead seal of the privilege; 6) Customary web-based visualisation tool for the 3D model of the seal.

Questo articolo presenta i risultati di un progetto di ricerca in Umanistica Digitale che esplora documenti d'archivio all'interno del sistema online *Engineering Historical Memory* (EHM) consentendo agli utenti di leggere fonti storiche primarie secondo diversi livelli di conoscenza e competenza in modo interattivo. Qui, come caso di studio, gli autori presentano la ricerca interdisciplinare (diplomatica, storia, visualizzazione 3D) che ha consentito la pubblicazione online dell'originale del privilegio concesso da papa Gregorio X alla comunità monastica del Monte Sinai nel 1274. L'applicativo comprende i seguenti strumenti di ricerca: 1)

ricomposizione digitale e restauro della campagna fotografico sulla pergamena originale che è conservata in due parti in due diverse località egiziane (Sacro Monastero di Santa Caterina al Monte Sinai e Archivio dello stesso monastero al Cairo); 2) *force-directed graph* per navigare la struttura diplomatica del privilegio papale; 3) visualizzazione geospaziale interattiva dei toponimi (viste satellitari e mappe politiche); 4) motori di ricerca accademici per testi, immagini e video relativi alle singole entità diplomatiche, storiche e geografiche identificate nell'applicativo; 5) modellazione 3D del perduto sigillo pendente in piombo del privilegio; 6) sistema sviluppato ad hoc per la visualizzazione sul web del modello 3D del sigillo.

Introduction

In recent years, the influence of visual imagery has advanced, and new tools and techniques have been increasingly exploited to the benefit of interdisciplinary research ([21]). Information visualisation has become an essential and meaningful approach for digital history to explore complex data sets ([9]: 5). It can be construed as a powerful guide for exploring primary historical information and generating new research opportunities to search in online secondary literature repositories ([11]). Nowadays, several visualisation solutions can be tested and successfully used by historians in their perennial chase for truth ([26]). Therefore, good information visualisation can help enlighten the relations among different historical information ([16]) to promote the sharing and participatory interpretation of historical memory.

Since 2007, Engineering Historical Memory (EHM) is an ongoing research project that welcomes international and multidisciplinary collaboration to design and test interactive applications for the virtual (re)organisation and delivery of historical knowledge in the digital age. The EHM research team studies and practises "by what means" traditional historical scholarship can supply machine-readable information. The aim is to empower historical sciences with artificial intelligence and machine learning, thus enabling all users to read primary historical sources according to different knowledge and expertise levels interactively. In the history domain, EHM makes a cross-disciplinary use of established research processes, such as mapping as understood in mathematics and linguistics (i.e., an operation that associates each element of a given set, the domain, with one or more items of a second set, the range) and parsing as understood in computing (i.e., analyse narratives into logical syntactic components) to kick-off the exploration of primary historical sources. Using these operations of mapping and parsing for individual primary historical sources, EHM associates each element of given sets of information provided by the domain of the traditional disciplines (e.g., history, art history, philology, palaeography, diplomatics, codicology, archaeology, epigraphy, sigillography) with one or more elements of the range of machine-readable content management systems (e.g., spreadsheets, computational notebooks).

The level of accuracy of this preliminary human activity is directly proportional to that of the aggregations generated and visualised by the EHM algorithms from different sets of similar written or depicted elements in the EHM database (e.g., geographical names, people's names, goods, ships, governments, events, architectures, drawings) and potentially relevant publications,

images, and videos retrieved in online repositories. To understand and emphasise the unity of EHM as an interactive system in the approach to historical information, the rhetorical and conceptual linking of “mapping and visualisation” as well as “search and visualisation” should be hendiadys. Thus, in its primary meaning, the term “mapping” is understood as the localisation and description of elements, facts or phenomena that relate to a circumscribed area, historically understood at the intersection of precise space and time coordinates. The aim is to provide and test an example of an innovative epistemological process to distil historical data visually. The “visualisation” process is seen not as a reductive representation to epitomise and/or illustrate written narratives but as an investigative tool that the historian (especially one who intends to enter fully into the digital era) can use for discovering and organising new relationships between objects, in a new historical landscape where past, present, and future can merge in a democratised whole. Refer to [2] and [8].

On EHM, five main types of information visualisation have been experienced as participatory opportunities for digital history. The application approached some best practices related to Radial Tree, Treemapping, Force-Directed Graph, OpenStreetMap and Satellite View in digital history to initiate a discussion. This exercise generated an information visualisation application that enables scholars to submit website reviews using an online template ([25]).

In this research context, the archival document has its peculiarity and needs to be investigated using the methods of three major academic disciplines: palaeography, diplomatics, and history. Usually, in academic literature, these disciplines explore and study the documents in research silos. This application can be construed as an answer to the critical question addressed and discussed in the webinar organised by the [Laboratorio di Cultura Digitale](#) and [EHM on 22 and 23 June 2020](#). This consideration is because this EHM application establishes a landmark in unifying the three multidisciplinary approaches to archival documents and providing a “digital humanities” interdisciplinary experience to the user. Refer to Figure 1. Identifying an alternative method for the digital processing of information embedded in archival documents relies upon the demonstration that archival documents are highly structured, and traditional disciplines can teach digital technologies how to decode the content and transfer it into a machine-readable and machine-understandable format. This process also addresses the second key question of the webinar, which was about creating digital editions of historical sources that do not respond to a single category of users, usually coinciding with that from which the edition itself originates. This EHM application shows how making information machine-understandable allows digital systems to satisfy different audiences simultaneously and the various queries that come from individual audiences under different circumstances.

The paper is structured in six sections (excluding this introduction). Section 1 presents the digital recomposition and restoration of the photographic survey of the original parchment, which is split into two pieces and held in two different locations in Egypt (Holy Monastery of St Catherine at Mt Sinai and the Archive of the same monastery in Cairo). Section 2 introduces the force-directed graph to navigate the diplomatics structure of the papal privilege. Section 3 illustrates the functions and operability of the interactive geospatial visualisations used for place names (satellite views and political maps). Section 4 describes the search engines for scholarly

texts, images, and videos related to the individual diplomatics, historical, and geographical entities itemised in the application. Section 5 showcases the 3D modelling of the lost lead seal of the privilege. Section 6 explains the development and implementation of the customary web-based visualisation tool for the 3D model of the seal. The paper ends with the acknowledgement of research collaborations and bibliographical references.

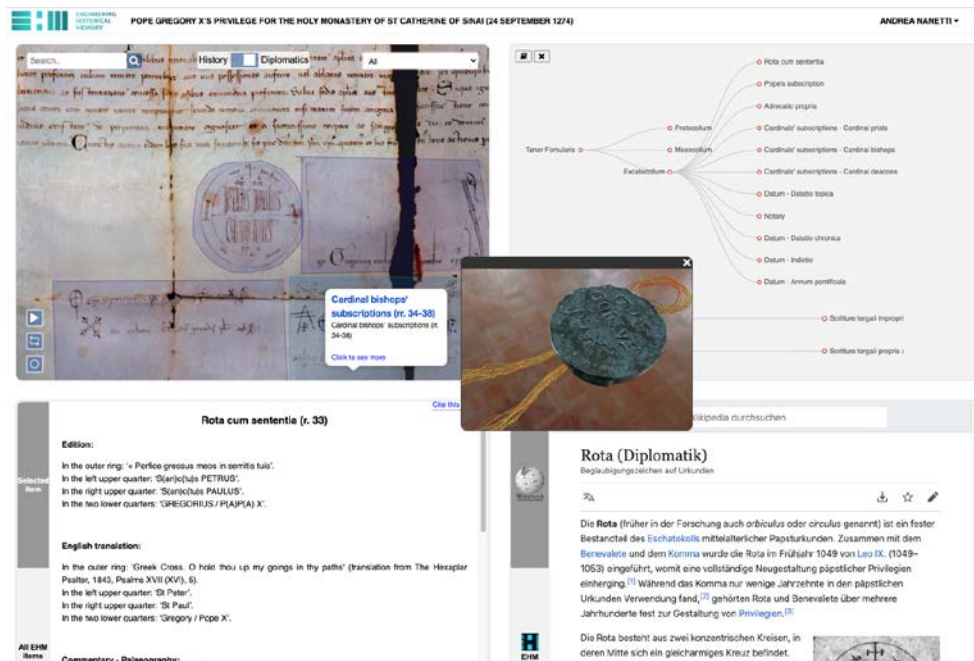


Figure 1: Screenshot from EHM. URL <https://engineeringhistoricalmemory.com/MountSinai.php?vis=sat>

1. Digital recomposition and restoration of the original parchment's photographic documentation¹

The original artefact is presently divided into two pieces: ink on parchment (ca 57x68cm), Ἱερὰ Μονὴ Θεοβαδίστου Ὁρους Σινά, Αγίας Αικατερίνης/Holy Monastery of St Catherine

¹ In this section, subsections 1.1, 1.2, and 1.3 are based on the report submitted by Andree Hanse Wibowo, who was tasked by Andrea Nanetti to digitally reconstruct a composite image of the document with the aid of an image editing software under the supervision of Davide Benvenuti. The steps detailed in this report can be construed as the most accurate and convincing image composite of the 1274 document based on the available photographs. While not perfect, this reconstruction has done justice at creating a reliable digital documentation of the original document for any future analysis and study of this Gregory X's privilege, until a new digital photographic campaign is done.

(Egypt), right part (ca 28.5x68cm) in the cabinet of the Archive of the monastery at Mount Sinai, left part (ca 28.5x68cm) in the strongbox of the Archive of the monastery in the *Metochion* (dependency) at Cairo. The overall state of preservation can be described as fair since the readability has not been affected, even if the supporting script has suffered minor mutilations that correspond to the intersections of the folds, three horizontal and three vertical ones, and is now bereft of the lead seal suspended from a silken thread. On both the front and the back, there are chancellery notes that document its archival life².

The digital reconstruction is based on the image information provided by the digitalisation of 27 analogue photographs capturing various sections of the 1274 privilege issued by Pope Gregory X for the monastic community of Mount Sinai³. When described as a different *version*, it means that the photograph could either be as follows.

- i. The same shot but colour corrected, rotated, or digitally manipulated in any other way to increase the visibility of certain features of the papal bull.
- ii. A different shot of the same section of the bull, with the same approximate angle and magnification.

Meanwhile, a *detail* or *zoom* shot means a closer shot or a zoomed-in crop of the same section of the bull, focused on a specific feature or point of interest. Regarding units with multiple versions, it is necessary to decide on one for the reconstruction process. Additionally, while the incorporation of detail/zoom shots is prioritised as much as possible, they may still be omitted when their image quality is equal to or lower than that of the photograph of the section. Deciding on which photo is most suitable for the reconstruction process is an exercise in trial-and-error and inevitably introduced some subjective artistic judgement. However, colour and image clarity are the two most deciding factors in the elimination process. It is often the case that unedited versions are preferable with colours as it retains more information potentially lost due to colour correction. It is also easier to achieve a coherent overall look with unedited versions than edited ones, which may have exaggerated unnatural colours or lighting quirks (Figure 2). How clear or sharp some images are, is often directly determined by the image size and resolution (Figure 3). To construct a composite image, the emphasis is put more on choosing sections that come together seamlessly as possible. Some areas heavily edited to increase the legibility of faded texts may not be incorporated into the composite but should still be used as a reference when trying to transcribe or decipher the writings in question. The necessary steps are then repeated until the final reconstruction is completed. In the following sections, each step is described in a more detailed manner.

Subsection 1.4 is based on the report submitted by Khoi Vu for the research assistantship supervised by Andrea Nanetti at *Engineering Historical Memory* in November 2020.

² The first critical edition was provided in 2008 (refer to [24]; and now, the online edition with commentary in English [27]). The document has not yet been included in Monasterium.net.

³ The software used is Adobe Photoshop® (PS). As the document's writing has a transverse course (i.e., parallel to the parchment sheet's minor side), the image is displayed vertically.



Figure 2: Photographed by Andrea Nanetti during a palaeographic mission of the Centre of History and Palaeography of the National Bank of Greece Cultural Foundation (Director, Agamemnon Tselikas, 19-24 January 1994). Digital reconstruction of the artefact by Andree Hansen Wibowo (May 2020). Copyright of the Holy Monastery of St. Catherine at Mount Sinai. The images of the papal bull have been first published with permission (Rev. Father Symeon, Librarian of the Monastery of St Catherine, and Agamemnon Tselikas, January 2001) as Tables 3-4 and 7-8 (right part) and Tables 1-2 and 5-6 (left part) in Nanetti, 2008. The images on the left show four of the original exaggerated shadows. The edited version's intense blue tinges on the right present a challenge in creating a coherent image composite.

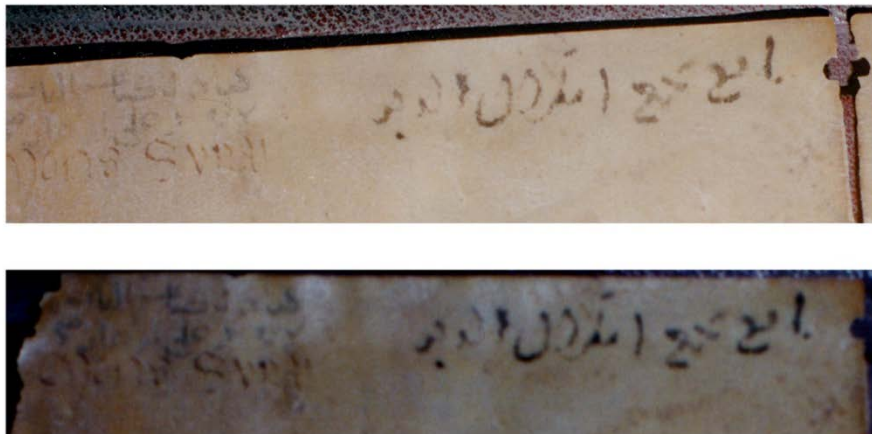


Figure 3: This is an example of decisions that had to be taken in the digital reconstruction. Although the detail below has a higher resolution and pixel size, it is apparent that the image above has an inherent greater clarity and would therefore be a more fitting photograph to be used for the image composite.

These images were used by Antonella Gherseti and Frédéric Bauden for the transcription, transliteration, and translation of the archival information in Arabic (refer to [27]).

1.1. Insert Photograph as Smart Object

This reconstruction leverages the Non-Destructive Editing (NDE) using Smart Object workflow available using Photoshop (PS from now on). This workflow allows retaining memory of an image's original state regardless of the number of edits applied to it.

1.1.1. Match Lighting and Colour

Figure 1 shows that the lighting of the papal bull sections is varied and uneven, so the best solution is to first adjust the segments' brightness to a commonly accepted standard. The photographs' non-standardised nature required multiple adjustment layers to achieve a unified look across all the different sections. In this adjustment process, Levels are an advanced version of Brightness/Contrast. It factors in the image's brightest highlights and darkest shadows instead of applying a sweeping brightening or darkening image. Curves is an even more fine-tuned version of Levels and has the added feature of allowing users to sample an image to copy its colour tone, which significantly aids the matching process. A clipping mask was set onto each adjustment layer to ensure that each adjustment layer only affects its targeted photographic segment.

1.1.2. Align Photographic Segments

Evaluating the photographed sections shows that adjacent segments overlap and present the same image information on the papal bull's specific areas. Theoretically, this makes it possible to position adjacent pieces and adjust them with each other until the overlapping areas align perfectly. However, perfect alignment is impossible due to the variance in the original photographs' lighting condition and lens magnification. Furthermore, the papal bull's physical condition did not provide consistent shapes across the different photographic sections. This characteristic makes the blending mode a helpful tool to indicate the degree of alignment between two photographic segments. If aligned well, we should see a strip of black where the two pieces overlap. Otherwise, we will see false colours where the two image layers misalign. This is also why the previous step standardises the lighting. A difference in the image brightness would be registered as a difference in colour under the Difference layer blending mode. Thus, with this Difference blend mode on, the next step was manipulating the scale, position and rotation of the photographic sections as needed, using each other as a marching guide. Refer to Figure 4 for an example.

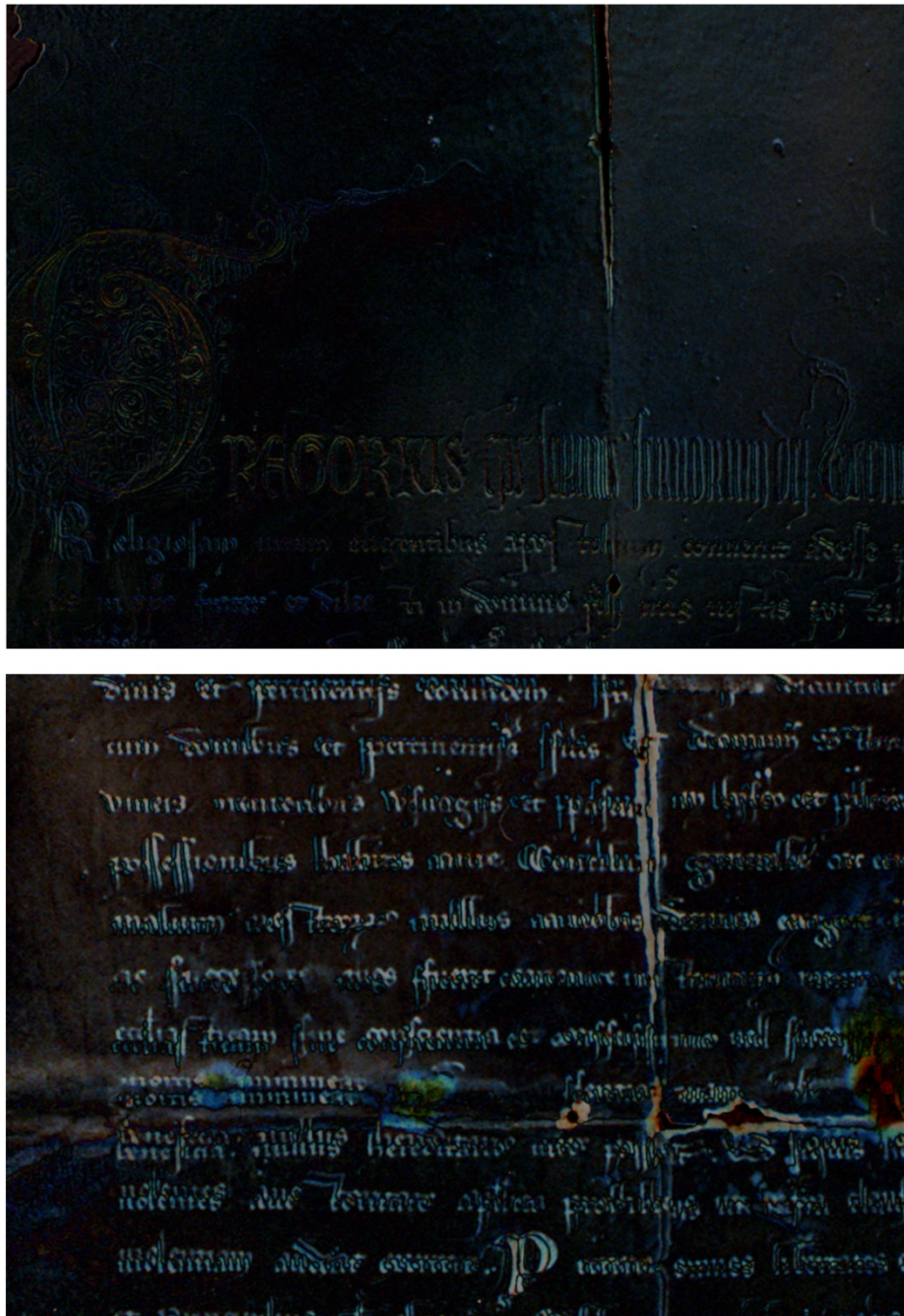


Figure 4: An example of a well-aligned section (Top) compared to a misaligned one (Below) under a 'Difference' blending mode.

The photographic segment's position, scale, and rotation were manipulated. Once the overlapping areas are satisfactorily aligned, the changes can be confirmed, and the layer blending mode can be turned back to Normal. This process restores the photographic segments' true colours in overlapping areas.

1.1.3. Create a Seamless Transition

After the photographic segments are adequately aligned, there may still be traces of misalignment or change in image brightness, manifesting as a break between the two elements. The subsequent creation of a Layer Mask allowed a smooth transition between the two segments. Layer Mask and masking allows to effectively 'erase' certain parts of a photographic segment's edge while still retaining the image information if it should be needed back in line with the Non-Destructive Editing principles. Finally, masking the image with a soft-edged brush integrates the two image segments with a gradual transition between slightly different brightness or lighting conditions.

1.2. Global Adjustments

Applying the previously outlined procedures to reconstruct both the recto (Figure 5) and the verso (Figure 6) of the papal bull, a relatively complete image composite of the provided photographs was obtained.



Figure 5: Recto (front side) of the 1274 Papal Bull issued by Pope Gregory X, work-in-progress.



Figure 6: Verso (backside) of the 1274 Papal Bull issued by Pope Gregory X, work-in-progress.

As shown in Figure 5 and Figure 6, although the primary form of the papal bull could be restored, still some imperfections are visible and compromise the appreciation of the content. Therefore, global adjustments would be required to tackle these imperfections, meaning that the edits performed in this stage are intended to affect the photographic segments. Instead of aligning two

or three pieces together, the adjustment aims to improve cohesiveness and coherence across all the photographic elements. The two main issues tackled in this stage are the following.

- i. Correct Alignment of Textual Information.
- ii. Extrapolation of Missing Paper Edges.

1.2.1. Correct Alignment of Textual Information

On the recto of the papal bull, a closer look at the image composite reveals that the textual information is not lining up correctly in certain areas due to the letter's creasing and tearing. Figure 7 and Figure 8 provide two significant examples.

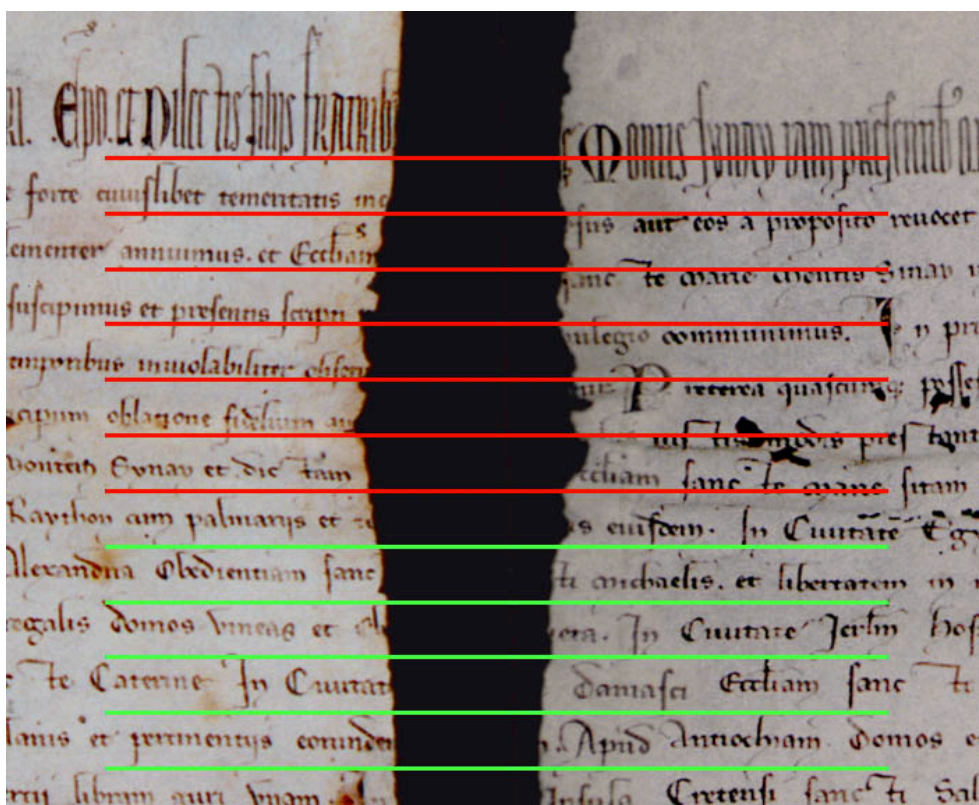


Figure 7: Example of how creasing causes some text to be misaligned.

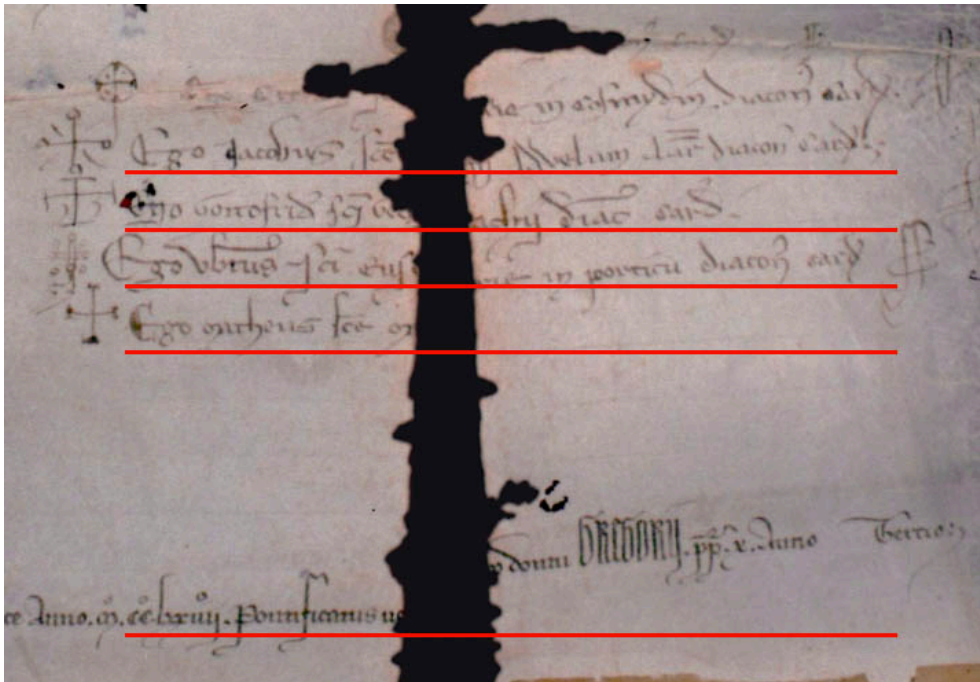


Figure 8: Example of how tears cause some text to be misaligned.

The correction of this imperfection requires selectively distorting parts of the image composite, which could be done in a few steps.

- i. The first step was to determine how much of the image composite should be distorted. This was done by considering the number of lines that are incorrectly aligned and the nature of the tear.
- ii. A selection will then be made of this part of the image composite. This selection will create both a layer mask and a duplicate of that area of the letter. See Figure 9 for an explanatory diagram.
- iii. The duplicated section is then made into a Smart Object to retain its original image quality before being distorted and warped to align with the letter's remaining areas.
- iv. Creating a seamless transition between the duplicated section and the remaining sections after aligning them is done using the same method described in Step 4 of the Image Reconstruction Process.

This process is repeated for all the misaligned textual information in the recto image composite until they are corrected.

Figure 9: (A) Area of the letter where selection is made is shown in red. (B) Layer Mask created using the section in (A). (C) Selection in (A) duplicated as a new image layer.

1.2.2. Extrapolation of Missing Paper Edges

Due to the photographs' framing, some document edges were not captured in the photographic sections. This lack of image information results in the image composite as abrupt hard edges (Figure 10).



Figure 10: Highlighted in cyan are examples of the straight edges on the recto (left) and the verso (right) because of missing photographic information in the photographic documentation.

When mirrored, the verso can add image information to the recto's edges and vice versa. Rather fortuitously, where the edge is missing on one side, it is present in the other, and as such, this extra information is enough to extrapolate how the missing edges might have looked like. The following steps would describe the extrapolation process using the verso as an example. The first step was to bring in the recto as a Smart Object layer and reflect it horizontally. The recto would then be transformed and distorted to fit the shape of the verso best, as shown in Figure 11.

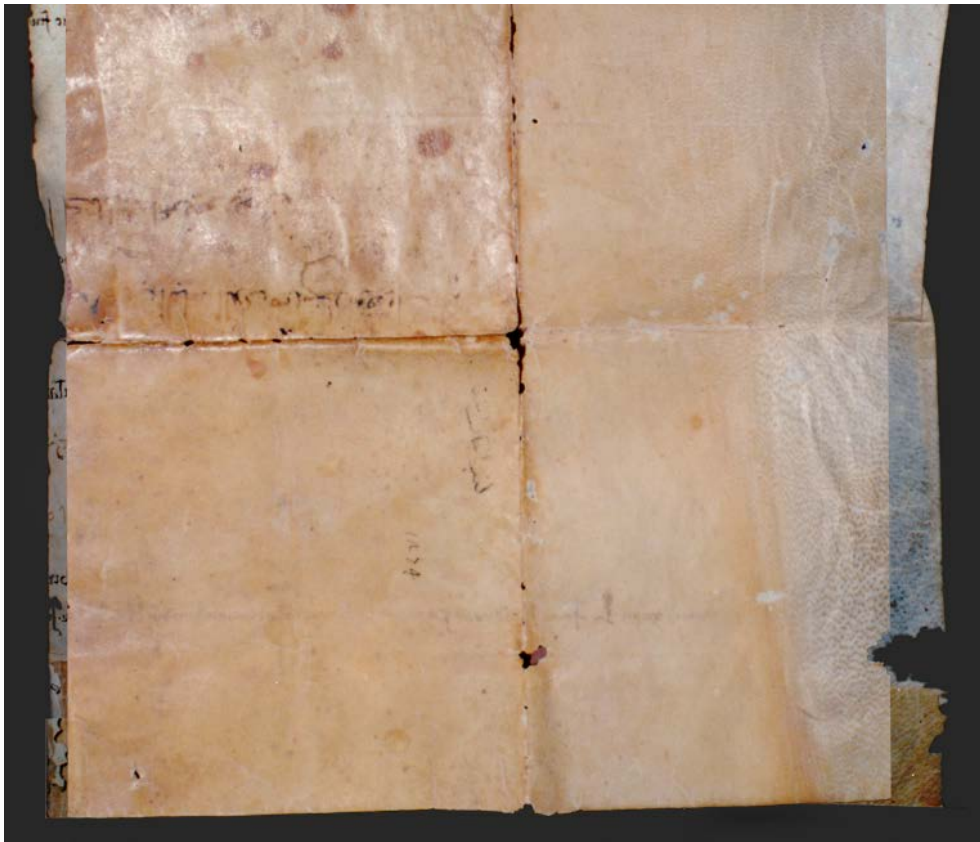


Figure 11: The mirrored recto, distorted to fit the form of the verso best and placed as a layer behind it.

A new layer was then created. The layer was masked to the shape of the mirrored recto and then used to recreate the verso's colour and texture using a combination of Stamp Tool and Spot Healing Brush Tool. While the Stamp Tool copies the sampled part of the image onto wherever the user chooses to apply it, the Spot Healing Brush Tool uses a process known as Content-Aware Sampling that automatically generates image information to blend away perceived anomalies based on the software's analysis of the image.

1.3. Result of the digital reconstruction

Figure 12 and Figure 13 show the digital recomposition and restoration of the original parchment's photographic documentation.

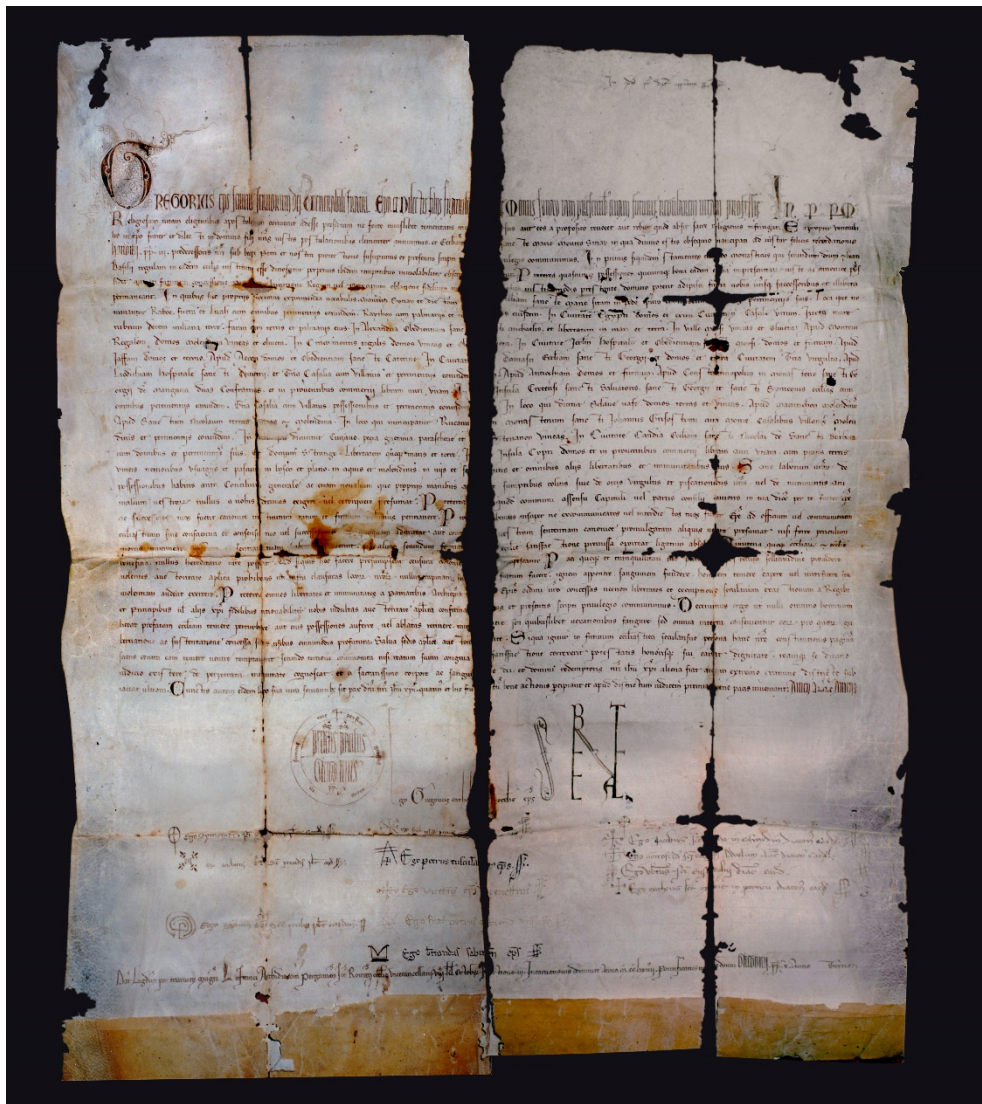


Figure 12: Recto of the 1274 Papal Bull issued by Pope Gregory X, result.



Figure 13: Verso of the Papal Bull issued by Pope Gregory X, result.

1.4. Result of the digital reconstruction

The web experience optimisation has been achieved through three meaningfully consequential actions: split, highlight, store.

1.4.1. Split

To provide easy and fast browsing of high-resolution images on webspace, EHM uses [Zoomify](#), which is both a format and a tool for deep zooming into high-resolution images. The tool resizes high-quality image into different lower resolution images, then splits them into smaller pieces with a fixed size of 256×256, which can be loaded partially corresponding to how users interact with the map. For example, the digitally reconstructed image of pope Gregory X's parchment has 3876×4335 pixels and is split as follows.

Layer 0: Width 387625121, Height 433525135 => 1 piece (121x135)

Layer 1: Image resized: Width 387624242, Height 433525270 ⇒ 2 pieces (one piece 242×256 and another piece 242x14)

Layer 2: Image resized: Width = 387623484, Height = 433523541 ⇒ 6 pieces (2 pieces 256×256, one piece 256x29, 2 pieces 228x256, 1 piece 228x29)

Layer 3: Image resized: Width = 387622=969, Height = 4335221083 ⇒ 20 pieces

Layer 4: Image resized: Width = 387621=1938, Height = 4335212167 ⇒ 72 pieces

Layer 5: Image resized: Width = 387620=3876, Height = 4335214335 ⇒ 272 pieces

This format allows a smooth, easy loading of the zooming level selected by the user. At the same time, it safeguards the copyright of the high definition original image, which is not available.

1.4.2. Highlight

This action aims to collect the “coordinates” of all items that the user can select on the original document and activate specific EHM tools and searches. The “coordinates” are a list of numbers that describe the points set on the digital document to identify the perimeter of individual items. The value of the numbers depends on the resolution of the image. A pair of two adjacent numbers constitute the abscissa and ordinate of the point. After that, the coordinates are transferred into a dedicated column of the Google Spreadsheet. The other information about the item is also saved (e.g., ID, title, commentary, English translation, etc.).

1.4.3. Store

The image pieces split by Zoomify are then stored on Microsoft Azure virtual machine (Linux).

2. Force-directed graph to navigate the diplomatics structure of the papal privilege⁴

The *tenor formularis* (i.e., the diplomatic organisation) constitutes the juridical structure of the archival document. It is essential for the historical reading of the document. This methodology is rooted in the diplomatics teaching imparted by Paolo Selmi at the School of Palaeography, Archival Studies, and Diplomatics of the *Archivio di Stato di Venezia*. However, most historians

⁴ This section is based on Andrea Nanetti's work ([24];[27]). The force-directed graph has been developed by Khoi Vu under Andrea Nanetti's supervision and is now accessible online interactively ([27]).

seem not to consider its importance because they lack diplomatics training. As a result, the historical information extracted from archival records does not clearly distinguish between standard formulas, common to all similar documents, and the formulas, which are peculiar to the specific *iuris actus* of the document.

On the other hand, the palaeographer and the diplomatist don't find it easy to retrieve the necessary historical contextualising information to read the *iuris actus* with other relevant documentation critically. Therefore, the EHM research team explored different visualisation methods to provide the historian with a clear and straightforward explanation of the *tenor formularis* and the palaeographer and diplomatist the relevant historical contextualisation. This double and complementary understanding of the primary source is now on the same page, and different disciplinary approaches can interact and discuss together.

The choice was to use a force-directed graph drawing algorithm to provide a clear and straightforward understanding of the *tenor formularis*. The force-directed graph is a class of algorithms for drawing diagrams in an aesthetically friendly way as well. The purpose of these algorithms is to position the nodes of a graph in two-dimensional or three-dimensional space so that all the edges are of equal length. There are as few crossing edges as possible by assigning forces among the set of edges and the set of nodes, based on their relative positions, and then using these forces to simulate the motion of the edges and nodes or minimize their energy.

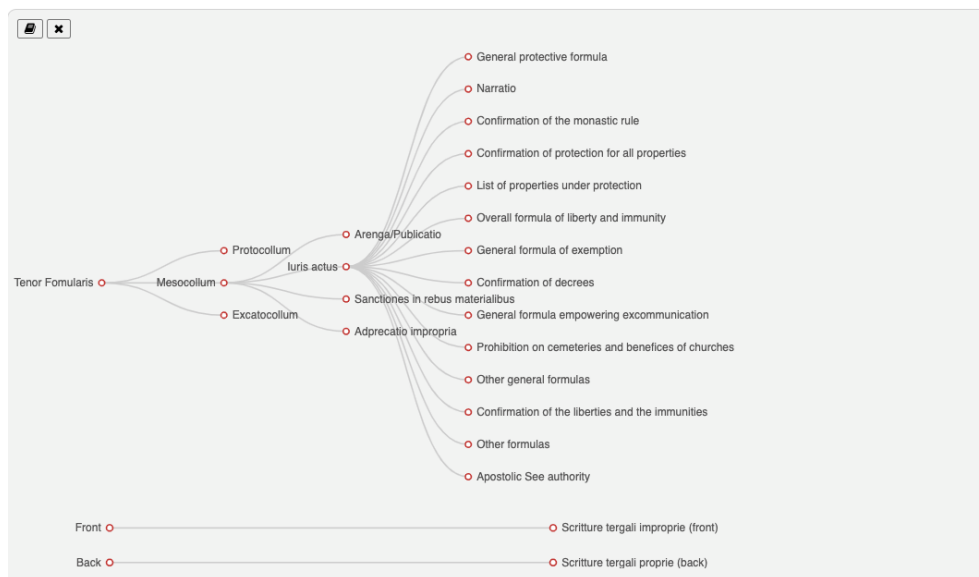


Figure 14: Screenshot of the interactive force-directed graph to navigate the papal privilege's tenor formularis (diplomatic structure).

The force-direct graph has been used here to visualise the methodology for the analysis of the *tenor formularis* (diplomatic structure) of a papal document that was taught to Andrea Nanetti by Paolo Selmi in the School of Palaeography, Archival Studies, and Diplomatics at the *Archivio*

di Stato di Venezia in 1991-1992 (refer to [24] and [27]). In the analysis of the *tenor formularis*, what arises continually is the similitudes with the privilege of Celestine III in favour of the *Canonica Portuense* of Ravenna dated 20 May 1196. This privilege renewed word for word the preceding ones of Innocent II, 1130-1143, and of Adrian IV, 1154-1159 (refer to Ravenna, *Archivio di Stato, Tabulario Portuensi*, Capsa C. Num. 671, published in [15]: 167-170, no. LXXXVII). This fact proves that the privilege for Mount Sinai uses the standard formulary put in place by the Holy See for privileges granted to monastic communities. A brief description of the *tenor formularis* is provided in the next subchapters. For a full appreciation of the document, refer to [24], Italian, and [27] in English.

2.1. Protocollum

The protocol (*protocollum*, r. 1) opens with the intitulation. The pope nominates himself without the ordinal number with the title of ‘*episcopus*’ and the formula ‘*servus servorum Dei*’, as usual in documents containing privileges. There follows in the dative case the inscriptio ‘*venerabili fratri episcopo et dilectis filiis fratribus Montis Synay ...regularum vitam professis*’. “The *papal letter regularum vitam eligentibus* is not found in the old book of the papal chancellery, namely in the *Liber diurnus*, but in that of the first half of the thirteenth century as a typical expression of the grant granted to the Cistercians. From 25 points of the Cistercian privilege, ten identical formulae are found in Mount Sinai’s privilege. At the same time, a further two are taken from the kind of papal privileges beginning with the words “*In eminenti Apostolicae Sedis specula*”. Refer to [19]: 286. The words “*regularum vitam professis*” also constitute the closure of the *inscriptio* in the above-mentioned privilege of Celestine III in favour of the *Canonica Portuense* dated 1196. Refer to [15]: 167-170). The usual honorary appellations used for bishops are observable (*venerabilis frater*) and for all the persons in general (*dilectus filius*), where the emperor and king had the address *charissimus in Christo filius* and ladies had *dilecta in Christo filia* (refer to [17]: 40). The protocol closes with the formula of perpetuity ‘in perpetuum’, which during this period substituted the salutation when the grant was accomplished, as is the case here, without limitations of time and place.

2.2. Mesocollum

In the text (or *mesocollum*), after the *arenga* (r. 2), which proceeds from the ‘*religiosam vitam*’ to ‘*infringat*’, there is a long multiple *iuris actus*, from ‘*Eapropter*’ (r. 2) to ‘*salva Sedis Apostolice auctoritate*’ (r. 29), in which the juridical act is expressed in the following arranged clauses.

2.3. Escatocollum

The closing section of the document (known as *escatocollum*, refer to [30]: 33-81) commences with the pope’s subscription, articulated in three separate elements arranged on the same line (r. 33, refer to [17]: 21-22).

3. Interactive geospatial visualisations of the place names (satellite views and political maps)⁵

The online application for pope Gregory X's privilege for the community of Mount Sinai (1274) used satellite view and OpenStreetMap. Satellite view provides image data obtained by photographing or scanning earth or other planets by various artificial earth satellites. It allows the contextualisation of historical-geographical data into the physical world. See an example in Figure 15. OpenStreetMap is an online mapping collaborative effort that provides user-generated street maps that can be free editable ([33]). It allows the contextualisation of historical-geographical data into the present political situation. See an example in Figure 15. The combination of these two tools provided a wealth of geographic data and spatial analysis.

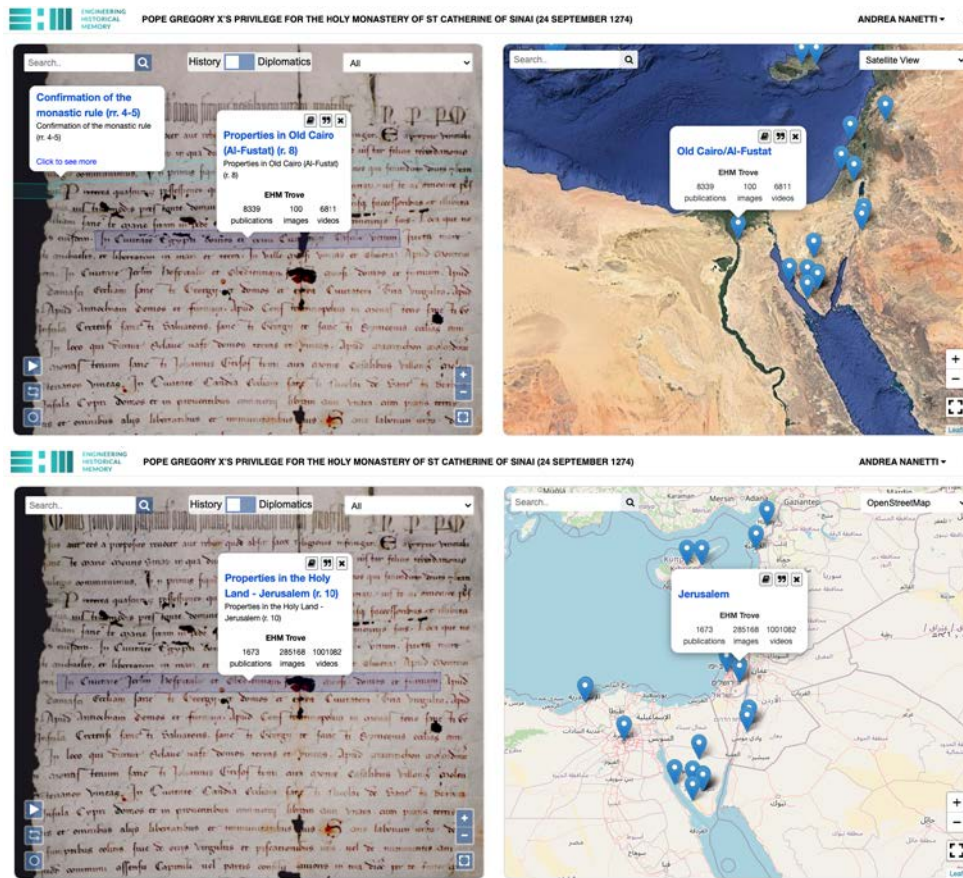


Figure 15: Screenshots of selected properties of the monastery in Cairo and Jerusalem show the connection between the document and the geospatial visualisation tools (satellite view for Cairo and OpenStreetMap for Jerusalem).

⁵ This section is based on the report submitted by Liu DanYun for Liu, DY., Nanetti, A., Vu, N. K. (Eds.). *EHM – Information Visualisation for Digital History*. Retrieved from <https://engineeringhistoricalmemory.com/Visualisation.php> (accessed on 2021-2-11).

4. Search engines for scholarly texts, images, and videos related to the individual diplomatics, historical, and geographical entities itemised in the application⁶

EHM has developed search algorithms to aggregate knowledge (Figure 16). Each item is identified using a relevant Wikipedia page whenever available. Based on this identification, EHM picks keywords and filters to aggregate knowledge from leading online repositories about any item selected by the user in the online application in real-time. Some of the resources are searched through their API (application programming interface), which is either public (e.g., Europeana, Gallica, YouTube, Vimeo, Google Images, Bing Images) or shared upon research collaboration agreement (e.g., Taylor & Francis, Scopus-Elsevier). Other online repositories do not have the policy to share their APIs for federated searches publicly. In these cases, the user is prompted to link to the official websites one by one in separate tabs; an automated query consistent with the selected item is automatically filled to facilitate the search. Online repositories without API are not included in the EHM search (e.g., SmartHistory). In EHM, the search results are visualised under four categories as follows.

- i. Scholarly publications from Europeana, Gallica, Taylor & Francis, Scopus-Elsevier, via API.
- ii. Images from Google Images, Bing Images, via API.
- iii. Videos from YouTube, Vimeo, I Media Cities, via API.
- iv. Guided search in other relevant resources that do not share their API publicly (e.g., GettyImages, Google Scholar, JSTOR, China National Knowledge Infrastructure, Wanfang Data, Pelagios, Blackwell)

With most of the resources, search APIs work by looking for input keywords in the digital documents accessible online (title, author, abstract, full text). Taylor & Francis also provides a cutting-edge service, which allows searching by “concept”. This means that the algorithm also searches the Taylor and Francis databases for concepts related to the set keywords.

⁶ This section is based on the report submitted by Khoi Vu for the research assistantship supervised by Andrea Nanetti at *Engineering Historical Memory* in November 2020.

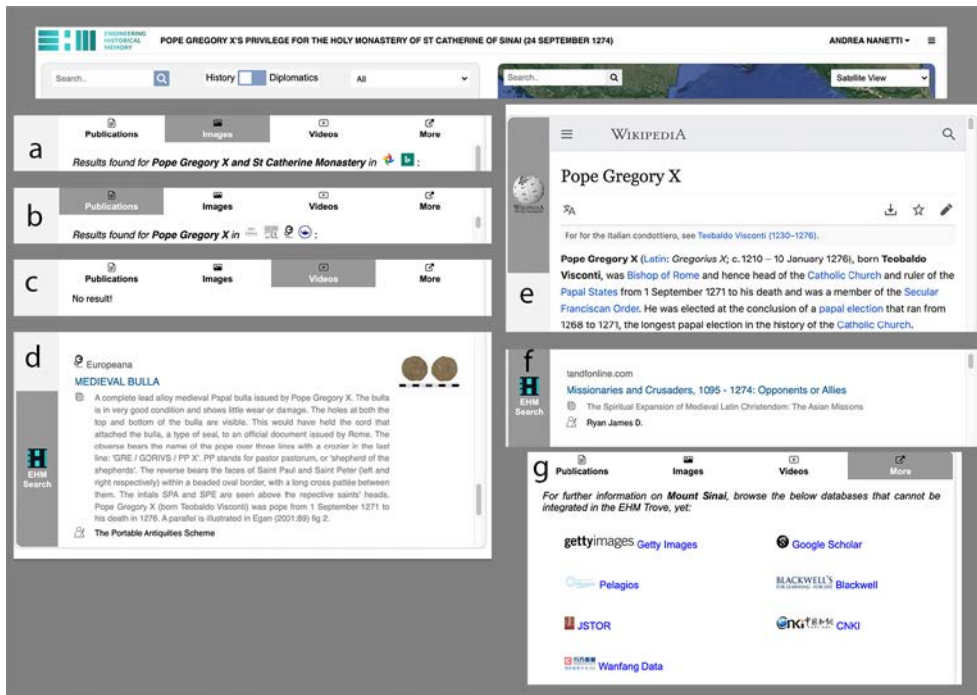


Figure 16: Screenshots of EHM Search Engines for scholarly texts (b, d, f), images (a), and videos (c) related to the individual diplomatics, historical, and geographical entities itemised in the online application for pope Gregory X's privilege for the monastic community of Mount Sinai (1274). The identifier of the item is the corresponding Wikipedia page (e).

Within EHM, the user can explore the digital images of primary historical sources and their critical editions and stay tuned with relevant secondary literature interactively and in real-time. These are two EHM essential innovations to approach the online publication of primary historical sources. In EHM, information is organised into two main streams: texts and images. In the case of Gregory X's document, the process started with the text of Andrea Nanetti's critical edition and commentaries (history and diplomatics; refer to [24]), whose information was transferred into a machine-readable format using Google Spreadsheet as a content management system and data storage solution because of several concurrent advantages: powerful, popular, secure, robust, customizable, easy backup, and, finally, the similarity with MySQL database in table-like construction. A diagram in Figure 17 illustrates the EHM workflow.

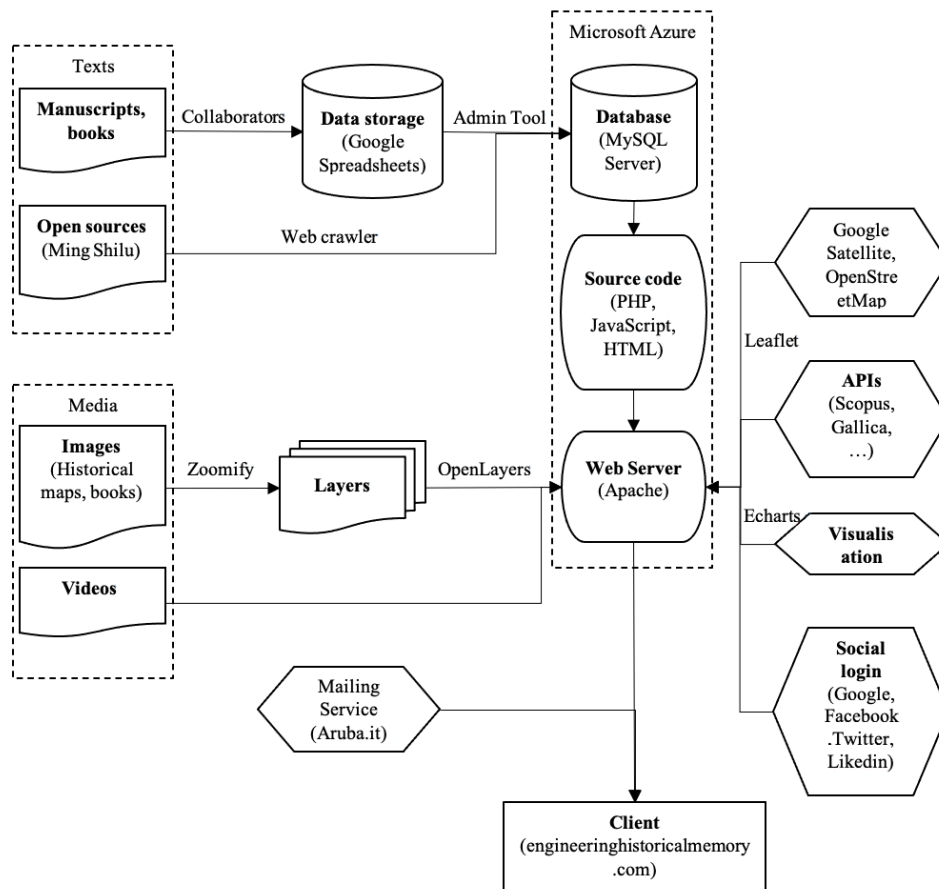


Figure 17: Workflow of the EHM search drawn by Khoi Vu.

5. Digital process for the 3D modelling of the lost lead seal of the privilege⁷

The parchment used as writing support, quite often, and above all whitened only on the part on which the text is placed, as is customary in bulls, allows one, together with the other usual intrinsic and extrinsic characters, to recognise the document as a solemn privilege and to suppose the presence of a lost leaden seal *cum filo serico* (with a silken cord, Figure 19), or rather *cum serico*, meaning by *sericum* a silken cord, consisting of numerous single threads partly red and partly yellow (for the *litterae cum serico* refer to [18]: 57-71, with footnote 9 at 57-58; for pontifical sigillography, refer to [31]; [4]; [20]). The *bullatores*, often illiterate, assigned a cord

⁷ This section is based on [24], [27], and on the report submitted by Yap Wei Wen Marc for the student work supervised by Davide Benvenuti.

of silk or hemp to a document based on the initial letter of the pope's name: if *cum spatiis et floribus erat* (it was with spaces and flowers), they used to assign a silken cord, and if *impleta incausto* (full of ink) then one of hemp (*cum filo canapis*; refer to [24]). Furthermore, the parchment shows the usual folds before the *plica* (i.e., surrounding cover) of the lower margin, where the two holes through which the *sericum* sealed with the lead must pass are still discernible.

Papal *bullae* acted as seals on official papal documents to authenticate their provenance and authority. On the bulls with leaden seals of Pope Gregory X still extant, we see two faces following the model fixed under Paschal II (1099-1118) and remaining unchanged after that (refer to [17]: 49). An example of “lead alloy Papal Bulla of Gregory X (date: 1271-76; diameter 37mm, thickness 5mm, weight 39.63g, excellent condition)” is in London, British Museum. A .jpg image is available under CC BY-SA 2.0 on the Wikipedia page of Pope Gregory X, with the note “thanks to The Portable Antiquities Scheme/The Trustees of the British Museum, File 2593”. However, according to the British Museum Images Account Manager, “any images available on Wikipedia are not authorised copies” (e-mail 24 June 2020). Refer to Figure 18.



Figure 18: Lead seal of Gregory X (*cum filo canapis*, **with hemp cord**). – **Obverse (left image)**. On the left, St. Paul is depicted with full facial features, long straight hair, and a beard. On the right, St. Peter is also shown with complete facial features and pellets from his curly hair and beard. Above the heads, the saints' abbreviations are still partially visible, with 'SPA' for St Paul to the left and 'SPE' for St Peter to the right. Both heads were separated by a tear-drop formation of linear beads, which surrounds the head motif with a cross pattée supported on a staff between them. – **Reverse**. GRE/GORIVS/PP X'. The description is based on [35]: 156, crediting Venice, Archivio di Stato, SS. Felice e Fortunato di Ammiana, in Procuratori di S. Marco 'de supra Canale', n. 136) © Archivio di Stato di Venezia, Procuratori di San Marco 'de supra Canale', b. 136 (Gregorius X, bulla plumbea cum filo canapis); digital images: courtesy of Dott. Gianni Penzo Doria.



Figure 19: Celestinus III (silk cord with colours faded by time). © Archivio di Stato di Venezia, Procuratori di San Marco 'de supra Canale', b. 136 (Celestinus III, bulla plumbea cum filo serico); digital images: courtesy of Dott. Gianni Penzo Doria.

To offer a complete reconstruction of the document, the research team decided to recreate a 3D model of the lost lead seal and an online costumery web system to visualise the model itself on the web, as shown in Figure 20. The work is based on different sets of 2D photographs of still extant lead seals held in the *Archivio di Stato di Venezia* taken by Gianni Penzo Doria on 20 July 2020. Firstly, to ensure that the scale is as accurate as possible, the dimensions (3.7cm by 0.5cm) of the seal were measured. A cylindrical polygon was used to block out the seal's basic shape and critical features in Autodesk® Maya®. Once the rough mock-up was mapped out, the mesh and geometry were later imported into the ZBrush® software for further detailing. Several problems arose from this process, mainly the alignment and the approximation of the coin to the source images. For example, the reference images were not orthographic in view.

Furthermore, a side-view image of the seal was not provided, causing the sculptor to rely mainly on a singular view as reference material. To alleviate this problem, several “back and forth rotating” or trial-and-error techniques were used to fit the mesh onto the source image to sculpt the seal's critical landmarks accurately. Most of the work was dedicated to carving the letters stamped on the seal. The sculpting of St Peter and St Paul's facial features was a less intricate process while compared to the letters. In sculpting, one must keep in mind the location of the ridges and the crease because the abbreviations themselves were not flat and had a particular extrusion value assigned individually. The geometry was exported as an 'FBX' into Substance Painter, where textures could be applied. After several colours, the generator achieved its final 'wear and tear rustic look', and the mesh was finally exported back into Maya for a final render, look and showcase.

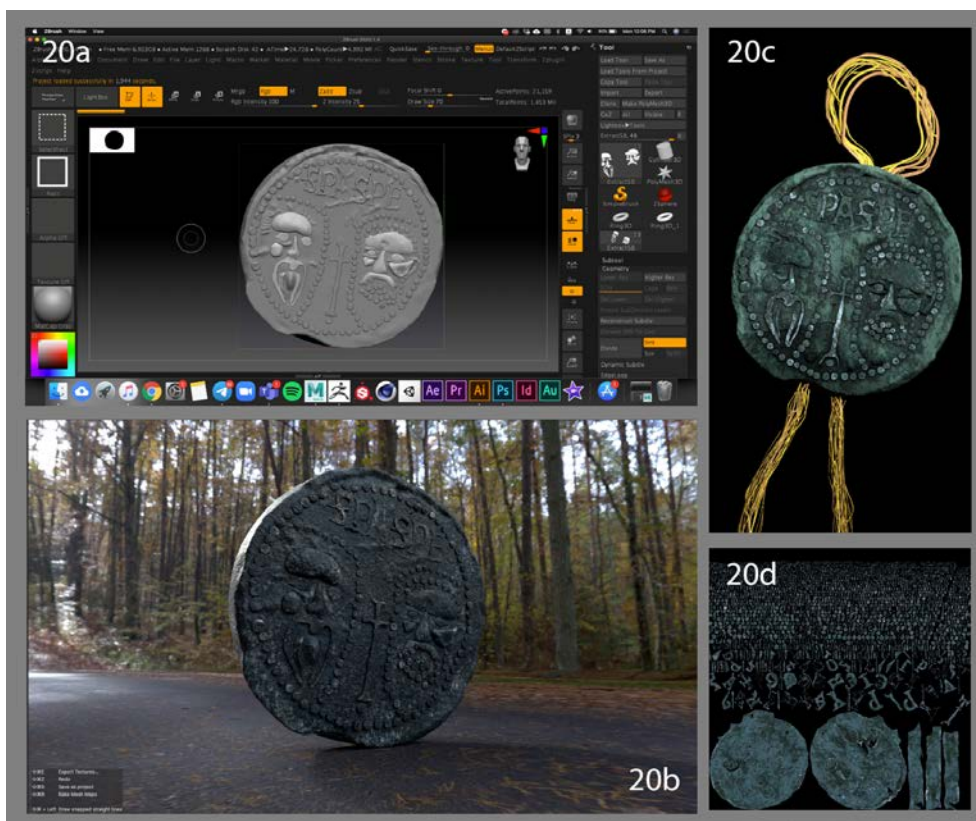


Figure 20: Screenshots of the ZBrush® interface with the model (20a); the finished model placed in a realistic environment to test realistic lighting render (20b); the 3D Model with the silk cord (20c); the texture mapping (UV Mapping) (20d). The work has been done by the NTU-ADM student assistant Yap Wei Wen Marc with the materials provided by Andrea Nanetti and under the supervision of Davide Benvenuti.

6. Creation of the customary web-based visualisation tool for the 3D model of the lead seal attached to the parchment with a silken cord⁸

Initially, the 3D model of the lead seal was uploaded onto Sketchfab™, an online platform used by content creators to post their 3D assets and make them accessible for public viewing (refer to [28]: 1-2; and [7]: 157). In the context of 3D rendering, three lights would have to be placed strategically to achieve this enhanced effect. Subsequently, vignettes, ambient occlusion and

⁸ This section is based on the report submitted by Xu Peisen for the student work at *Engineering Historical Memory*.

depth of field effects were added to adjust the post-processing before publishing the model. As far as Sketchfab™ is not open access, EHM opted to create a dedicated JavaScript code of the model was later copied and prepared for embedment onto the EHM website.

The costumery creation of a web display platform for 3D object represents a step forward in making the EHM platform open access as using from the shelf software has limitation regarding the amount of data that can be uploaded and the number of visualisations that can be allowed. One major limitation hurdle in creating a customary interface is the loading time of the object is heavily dependent on the size of the file. The research team had to strike a compromise between the quality of the display and the time that the user will have to wait for the object to appear. After several tests run by the EHM research team, the loading time of the model and page took nine seconds. Hence, more work needed to be done to optimise the window's position in the user interface of the 3D model; for example, making the 3D model's display as an option for the user to toggle with or testing out a larger polycount and file size. Further troubleshooting was necessary to test the loading time of the model. This was done by adjusting the scaling and textures accordingly. The file was later converted into the Graphics Language Transmission Format or 'glTF' as a recommended workflow by the developers at 'three.js'.

Conclusions

In conclusion, this EHM application pioneers and tests a new set of methods to explore the complexity of archival documents in a web environment interactively. EHM is free and open access. Within EHM, the user can explore the digital images of the document along with their critical editions and stay tuned with relevant secondary literature interactively. This methodology is rooted in the diplomatics teaching imparted by Paolo Selmi at the School of Palaeography, Archival Studies, and Diplomatics of the *Archivio di Stato di Venezia*. Based on this knowledge, EHM has engaged a multidisciplinary team for diplomatics, history, digital image reconstruction, web development, animation, and customary web-based visualisation. This application is a scalable model for teaching and research projects in the palaeography and diplomatics of the papal document, history of the relationship among Venice, Rome, and Mount Sinai, and digital humanities at large.

This interdisciplinary identification of an alternative method for the digital processing of information embedded in archival documents achieved results so far unexplored. The theory is that technology should serve traditional disciplines and not vice-versa. In practice, as fewer coding skills we require to the historian, the better it is. In the case of the papal bull of Gregory X published in EHM, the juridical structure of the archival document is made available together with the historical information in two distinct but interactively communicating datasets. The EHM research collaborators have access to the semi-structured data from the source. Using the Excel spreadsheet as a content management system is the sole tech skill required to the diplomatist and the palaeographer to make their knowledge machine-readable and machine-understandable.

On this basis, the EHM algorithms follow up and aggregate the information visually. On EHM, five main types of information visualisation have been experienced as participatory opportunities for digital history. The application approached some best practices related to Radial Tree, Treemapping, Force-Directed Graph, OpenStreetMap and Satellite View in digital history to initiate the discussion. Thus, the historian can rely on a digital system to be aware of the juridical structure of the archival document and clearly distinguish between repetitive formulas common to all similar documents and the clauses, which are peculiar to the specific document under examination. At the same time, more skilled historians have at their disposal all the tools to go back to the original document and make an individual (re)reading of all potentially controversial aspects. The results can be shared on the same platform and generate a discussion without involving traditional journals that fragment and delay the advancement of learning.

Therefore, this process also addresses a second critical question about publishing historical sources without responding only to a single category of users, usually coinciding with that from which the edition itself originates. EHM demonstrates how making information machine-understandable allows digital systems to satisfy different audiences simultaneously because of the different layers of information. Furthermore, the system can be used in different settings (e.g., portable devices, desktop computers, large interactive screens, projection mapping) and answer various queries from individual audiences under different circumstances. Finally, on EHM, the historian cannot adopt a manipulative selection of information. Individual historians can build their narrative, write their stories in a system that highlights what has been selected, neglected, and ultimately how historical information becomes historical knowledge with given authorship.

Acknowledgements

Andrea Nanetti has photographed the original parchment during a palaeographic mission of the Centre of History and Palaeography of the National Bank of Greece Cultural Foundation (Director, Agamemnon Tselikas, 19-24 January 1994). The images of the papal bull have been first published with permission (Rev. Father Symeon, Librarian of the Monastery of St Catherine, and Agamemnon Tselikas, January 2001) as Tables 3-4 and 7-8 (right part) and Tables 1-2 and 5-6 (left part) in Nanetti, 2008. Further reproduction is prohibited without the permission of the copyright owners. The first critical edition and commentary of this document have been published by Andrea Nanetti, *L'originale del privilegio Religiosam vitam di papa Gregorio X per il Monte Sinai (1274). Edizione e commento*, in *Studi di storia del Cristianesimo. Per Alba Maria Orselli*, edited by Luigi Canetti, Martina Caroli, Enrico Morini, Raffaele Savigni. Ravenna: © A. Longo Editore (Le Tessere, 16), [July] 2008, pp. 235-268, with 13 plates (pp. 209-217). The paper has been translated into English by Nicolas Coureas and Andrea Nanetti. Nanyang Technological University Singapore has funded the translation work of Nicolas Coureas (StartUp Grant 2014-2016, M4081357, PI Andrea Nanetti) and published with the permission of A. Longo Editore on *Engineering Historical Memory*. The original parchments' digital reconstruction was accomplished by the NTU-ADM undergraduate student Andree

Hansen Wibowo in May 2020. The modelling of the lost lead seal of Gregory X was made by the NTU-ADM undergraduate student Yap Wei Wen Marc in November 2020. Both students were engaged as student training assistants supported by the Ministry of Education, Singapore, under its Academic Research Fund Tier 1 (PI Andrea Nanetti, 2017-2020, RG55/17NS). The modelling of the lead seal was based on images of the papal lead seals provided by the *Archivio di Stato di Venezia, Procuratori di San Marco 'de supra Canale'*, b. 136 (Gregorius X, *bullae plumbea cum filo canapis*; Celestinus III, *bullae plumbea cum filo serico*; Innocentius III, *bullae plumbea cum filo serico*); digital images: courtesy of Dott. Gianni Penzo Doria. The NTU-ADM graduate student Xu Peisen created the customary web-based visualisation tool for the 3D model of the lead seal attached to the parchment with a silken cord and uploaded it on *Engineering Historical Memory* in collaboration with the NTU-ADM research assistant Khoi Vu funded by the Tier 1 grant mentioned above. Last but not least, the research associate Zaqeer Radzi assisted in formatting the text and the bibliographical references according to the *Umanistica Digitale* guidelines under the SGUnited Traineeship Programme.

References

- [1] Adjustment and fill layers in Photoshop (2017): <https://helpx.adobe.com/photoshop/using/adjustment-fill-layers.html>.
- [2] Altman, R. 2008. *A theory of narrative*. New York: Columbia University Press.
- [3] Baaken, G. 1970. "Die Verhandlungen Kaiser Heinrichs VI. Und Papst Coelestins III". *Deutscher Archiv* 27: 479-513.
- [4] Bascapè, G. C. 1978. *Sigillografia. Il sigillo nella Diplomatica, nel Diritto, nella Storia e nell'Arte*. Vol. 2. *Sigillografia ecclesiastica*. Milano: Giuffrè.
- [5] Bertin, J. 2010. *Semiology of Graphics: Diagrams, Networks, Maps*. Redland: ESRI PRESS.
- [6] Bock, F. 1953 "Problemi di datazione nei documenti di Gregorio X". *Rivista di Storia della Chiesa in Italia* 7: 302-336.
- [7] Birn, J. 2013. *Digital Lighting and Rendering*. Berkeley, California: New Riders.
- [8] Bolick, C. M. 2006. "Digital Archives: Democratizing the Doing of History". *International Journal of Social Education* 21 (1): 122-134.
- [9] Cheng, X., He, H., Ren, Y., & Ba, S. 2020. "Teaching Discussion on Information Visualisation Design." *International Conference on Human-Computer Interaction*, 393-404. Springer: Cham.
- [10] Claverie, P. V. 1998. "Un aspect méconnu du pontificat de Grégoire X: les débuts de sa politique orientale (1271-1273)". *Byzantion* 68 (2): 281-310.
- [11] Cohen, D. J. 2008. "Interchange: The Promise of Digital History". *Journal of American History* 95 (2): 452-491. <https://doi.org/10.2307/25095630>.
- [12] Create layers in Photoshop Elements (2018): <https://helpx.adobe.com/photoshop-elements/using/creating-layers.html>.

- [13] Evangelisti, P. 2001. “Un progetto di riconquista e governo della Terrasanta: strategia economica e militare e proposta di un codice etico-politico attraverso il lessico regolativo-sociale minoritico”. In *Alle frontiere della cristianità: I frati mendicanti e l'evangelizzazione tra '200 e '300. Atti del XXVIII Convegno internazionale della Società internazionale di studi francescani (Assisi, Centro interuniversitario di studi francescani, 12-14 October 2000)*, 135-199. Spoleto: Fondazione Centro italiano di studi sull'alto Medioevo.
- [14] Duba, W. O., & Schabel, C. D. 2015. *Bullarium Hellenicum. Pope Honorius III's Letters to Frankish Greece and Constantinople (1216-1227)*. Turnhout, Belgium: Brepols Publishers.
- [15] Fantuzzi, M. 1802. *Monumenta ravennati de secoli di mezzo per la maggior parte inediti*. Vol. 2. Venezia: Francesco Andreola.
- [16] Fan, L., Bo, H., Li, F., & Sui, J. 2020. “Information Visualisation Design for Museum Exhibition Panels.” *Journal of Dongnan Culture* 4: ___-___.
- [17] Frenz, T. 1998 *I documenti pontifici nel medioevo e nell'età moderna* [Translation by Pagano, S., & Santoro, V. of Frenz, T. 1986. *Papsturkunden des Mittelalters und der Neuzeit*. Wiesbaden-Stuttgart: Franz Steiner Verlag]. Città del Vaticano: Scuola Vaticana di Paleografia, Diplomatica e Archivistica.
- [18] Herde, P. 1967. *Beiträge zum päpstlichen Kanzlei- und Urkundenwesen im dreizehnten Jahrhundert. Zweite, verbesserte und erweiterte Auflage*. Kallmünz/Opf.: Verlag Michael Lassleben.
- [19] Hofmann, G. S. I. 1951 “Lettere Pontificie edite ed inedite intorno ai monasteri del Monte Sinai”. *Orientalia Christiana* 17: 302-303.
- [20] *Il sigillo nella storia della civiltà attraverso i documenti dell'Archivio segreto vaticano. Mostra documentaria, 19 febbraio-18 marzo 1985: testo in italiano con sommario in francese, inglese, tedesco, spagnolo*. Città del Vaticano: Tipografia poliglotta vaticana, 1985.
- [21] Jensen, H. S. 2020. “Digital Archival Literacy for (all) Historians.” *Media History* <https://doi.org/10.1080/13688804.2020.1779047>.
- [22] Laurent, V. 1940. Rome et Byzance sous le pontificat de Célestin III (1191-1198). In *Échos D'orient* 39: 26-58.
- [23] Pfaff, V. 1974. “Das Papsttum in der Weltpolitik des endenden 12. Jahrhunderts”. *Mitteilungen des Instituts für Österreichische Geschichtsforschung* 82: 338-376.
- [24] Nanetti, A. 2008. “L'originale del privilegio Religiosam vitam di papa Gregorio X per il Monte Sinai (1274). Edizione e commento.” In Canetti, L., Caroli, M., Morini, E. & Savigni, R. (Eds.). *Studi di storia del Cristianesimo. Per Alba Maria Orselli*, 235-268, with 13 plates at 209-217. Ravenna: A. Longo Editore.
- [25] Nanetti, A., Liu, D., & Vu, N. K. eds. 2010. *EHM – Information Visualisation for Digital History*. Retrieved from: <https://engineeringhistoricalmemory.com/Visualisation.php> (Accessed on 2021-2-4).
- [26] Nanetti, A., & Cheong, S. A. 2018. “Computational History: From big data to big simulations”. In *Computational Social Science and Humanities*, 337-363. Springer: Cham.

- [27] Nanetti, A., & Vu, N. K. eds. 2020. *EHM – Pope Gregory X's Privilege for the Holy Monastery of St Catherine of Sinai*. Retrieved from: <https://engineeringhistoricalmemory.com/MountSinai.php> (Accessed on 2021-2-4).
- [28] Pharr, M., Jakob, W., and Humphreys., G. 2016. *Physically Based Rendering: from Theory to Implementation*. Amsterdam; Boston; Heidelberg: Elsevier.
- [29] Rabikauskas, P. S. I. 1998. *Diplomatica pontificia (Praelectionum lineamenta): ad usum auditorum*. VI ed. emendata et aucta (first edition 1964). Roma: Ed. Pontificia Università Gregoriana, Facultas Historiae Ecclesiasticae.
- [30] Rodolico, N. 1990 *Note paleografiche e diplomatiche sul privilegio pontificio (da Adriano I a Innocenzo III)*. Bologna: N. Zanichelli.
- [31] Serafini, C. 1910-1928. *Le monete e le bolle plumbee pontificie del Medagliere Vaticano: Storia della collezione di St. Le Grelle e tavole*. Milano: Hoepli.
- [32] Wibowo, A. H., Benvenuti, D., & Nanetti, A. 2020. *Entry 'Digital Recomposition of Pope Gregory X's Privilege for the Community of Mount Sinai'*. In *Nanetti, A., Vu, N. K. (Eds.). EHM – Pope Gregory X's Privilege for the Holy Monastery of St Catherine of Sinai (24 September 1274)*. Retrieved from: <https://engineeringhistoricalmemory.com/MountSinai.php?vis=sat&video=1> (Accessed on 2021-2-4).
- [33] Haklay, M., Weber, P. “OpenStreetMap: User-Generated Street Maps”. In *IEEE Pervasive Computing*, 7(4), 12-18. Oct.-Dec. 2008. <https://doi.org/10.1109/MPRV.2008.80>.
- [34] *Decretum Gratiani 1735*. Pauli Bornagii, *Concordia discordantium canonum, sive symphonia articularum Augustanae Confessionis cum canonibus decreti Gratiani*. Berlin: Rüdiger. URL: <https://geschichte.digitale-sammlungen.de//decretum-gratiani/online/angebot>
- [35] Ricci, S. 1985. *Il Sigillo nella storia e nella cultura [Catalog of the exhibition held in Venice at the Correr Museum between 6 July and 31 August 1985]*. Sesto San Giovanni, Milano: Jouvence.