The Journal of
HISTORICAL
NETWORK
RESEARCH

9 | 2023
special issue

Networks of Manuscripts, Networks of Texts

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C²DH
LUXEMBOURG CENTRE FOR
CONTEMPORARY AND DIGITAL HISTORY

UNIVERSITY OF
LUXEMBOURG

Imprint

Université du Luxembourg 2023

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ISSN 2535-8863

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Published online at
https://doi.org/10.25517/jhnr.v9i1

The Journal of HISTORICAL NETWORK RESEARCH

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Scribal networks

Visualizing twelfth-century Cistercian book production through network analysis

Journal of Historical Network Research 9 (2023) 101–129

Keywords Paleography, Cistercians, library history, Magnum Legendarium Austriacum, Medieval Studies, Manuscript Studies

Abstract This paper tests the application of network analysis to the visualization and analysis of paleographical data. In recent years, the twelfth-century scriptoria of the Austrian Cistercian monasteries of Heiligenkreuz, Zwettl and Baumgartenberg have been thoroughly investigated. A vast amount of data on scribes and their contributions to various manuscripts has been published in analog publications, as well as online on the website www.scriptoria.at, run by Alois Haidinger. The presentation of the data, mainly in the form of lists, makes it difficult for researchers to appreciate the possibilities that this groundbreaking work provides. For this paper, the data is instead presented as networks of codicological units and networks of scribes within and between the monasteries. These networks highlight the development and interconnectedness of twelfth-century Cistercian book production, point out potential research questions (e.g., for the *Magnum Legendarium Austriacum*), and aid in disseminating the results to a wider audience.

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Introduction

Recent research has provided a vast amount of data on the scribes who copied books in Austrian monasteries in the twelfth century. By evaluating their collaboration and tracking single hands across many manuscripts, it has become possible to reconstruct the scriptoria of three Cistercian monasteries (Heiligenkreuz, Zwettl and Baumgartenberg). In this paper, the available data is used to showcase how network analysis can help to present these reconstructions in a reader-friendly form and point out further research questions.

In the first part, the three monasteries chosen for this research are introduced, along with their libraries. In part two, the data sources and the steps towards network analysis with Gephi are discussed. Part three addresses questions of data quality and completeness. Part four presents network diagrams for the Heiligenkreuz scriptorium, as well as for all three scriptoria combined. These include networks of scribes and of codicological units. Finally, part five discusses the application of network analysis for investigating manuscript and scribal transfer, using the example of *Magnum Legendarium Austriacum* and *De sacramentis* by Hugh of St. Victor.

1. Historical background

The arrival of monks from Morimond in the Viennese Woods, along with the foundation of Heiligenkreuz in 1133, led to a quick expansion of the Cistercian order in northern Austria. In 1138 the first daughterhouse, Zwettl, was founded, followed by Baumgartenberg in Upper Austria in 1141/2.[1] The large number of still extant manuscripts shows that all three monasteries started to establish new libraries shortly after their foundation.[2]

For Heiligenkreuz, a book list compiled during the abbacy of its first abbot Gotschalk (1133–1147) provides detailed information on about 70 manuscripts

Acknowledgements: I like to thank the libraries and librarians in Heiligenkreuz (P. Roman Nägele), Zwettl (Andreas Gamerith) and the State Library of Upper Austria. Without their continuous support, my work would not be possible.
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1 There is no modern overview on the history of the Cistercian order in Austria. Short entries for each monastery can be found in Zák, *Österreichisches Klosterbuch,* 109–39. Some aspects of the early history of Heiligenkreuz and Zwettl are discussed in Lutter, "Zisterzienser."

2 Manuscripts from Heiligenkreuz are today kept in the monastery's own library as well as the Austrian National Library, manuscripts from Zwettl are kept in Zwettl, while manuscripts from Baumgartenberg can be found in the State Library of Upper Austria as well as the Austrian National Library.

that formed the monastery's early library.[3] The list does not mention liturgical books, which clearly existed but were probably kept in another room and only survive as fragments.[4] In the late fourteenth century, another detailed book list was compiled that yet again makes it possible to identify extant books as coming from Heiligenkreuz.[5] Overall, about two-thirds of the manuscripts mentioned in the book lists survive.[6]

The high medieval book lists for Zwettl are less detailed and therefore more difficult to interpret. A list from the late twelfth century mentions works by Augustine with no clear indication that those works were actually part of the library. It seems very likely, however, since the manuscript that contains the list can be identified as its last entry.[7] This entry also shows another shortcoming of the list: it does not indicate which works were combined into one volume. Another list from the first half of the thirteenth century poses a similar challenge. It clearly states that the books were part of the library, but only mentions one text per volume.[8] If each entry stands for one manuscript, then the list contains over 100 volumes. As in Heiligenkreuz, liturgical books are not included. Finally, another contemporary list contains all the works by Augustine held in Zwettl.[9] There are discrepancies in the number of works by Augustine between all lists, which sheds some doubt on their reliability.[10] The identification of extant manuscripts with entries in the book list is referenced in the modern manuscript catalogue, but has not been reevaluated for this study.[11]

The library of Baumgartenberg was much smaller than those of its motherhouse and sisterhouses. An early thirteenth-century book list provides detailed descriptions of nearly 70 non-liturgical manuscripts (if multi-volume manu-

3 Edited in Gottlieb, *MBKÖ 1,* 18–21. A detailed discussion of discrepancies and issues with identification, as well as a table of identified manuscripts, can be found in Haidinger and Lackner, *Bibliothek,* 10–18.

4 See for instance Cod. 176, fol. I, or a group of fragments of a breviary called Fragmentgruppe Cod. 7, at: https://www.scriptoria.at/cgi-bin/scribes.php?ms=AT3500-FragmC7 (accessed May 25, 2022).

5 Gottlieb, *MBKÖ 1,* 34–74. At about the same time, an inventory of all bookcases was also drawn up (edited Ibid., 22–33).

6 The exact number is difficult to determine since some of the entries cannot firmly be identified with extant manuscripts.

7 Gottlieb, *MBKÖ 1,* 510–11.

8 Gottlieb, *MBKÖ 1,* 511–14.

9 Gottlieb, *MBKÖ 1,* 514–16.

10 Discussed by Gottlieb.

11 Ziegler, *Zisterzienserstift Zwettl.* No new attempts to identify the entries in the book list have been carried out since Ziegler. An upcoming publication on the Zwettl scriptorium by Alois Haidinger will most likely shed more light on this question (see footnote 59).

scripts are counted separately).[12] In addition, several liturgical manuscripts are listed that are lost today.[13] Contrary to Heiligenkreuz and Zwettl, Baumgartenberg is no longer active; it was closed in 1784 as part of the dissolution of monasteries during the reign of emperor Josef II. Its library was dispersed and partly sold off in the late 1780s. Most, if not all, parchment manuscripts that were kept in it at the time of the dissolution are today part of the collections of the State Library of Upper Austria and the Austrian National Library. However, less than 50% of the manuscripts mentioned in the book list are still extant, which points to earlier losses.[14]

Recent paleographical studies, discussed in more detail below, have shown that a large number of extant manuscripts from Heiligenkreuz and Zwettl, and to a lesser extent from Baumgartenberg, that are mentioned in the book lists were produced by the respective scriptoria.[15] These investigations also point towards exchange processes between the scriptoria, such as manuscript transfer and, more importantly, the transfer of scribes. Overall, these manuscripts therefore provide a perfect case study for possible interactions between motherhouses, daughterhouses and sisterhouses as far as book production is concerned, as well as for the development of scriptoria in twelfth-century Cistercian monasteries in general.[16]

12 Some entries are slightly later additions. The list is edited in Paulhart, *MBKÖ 5,* 14–18 (with manuscript identifications).

13 A few fragments survived in manuscript bindings, see e.g., Vienna, Austrian National Library, Cod. 671.

14 A very short introduction to the history of Baumgartenberg's library can be found in Paulhart, *MBKÖ 5,* 13–14; Kaska, "Schreiber und Werke," 63–64. Early modern shelfmarks indicate that there were more paper manuscripts extant at the time of the dissolution than survive today. This topic will be discussed in more detail in future publications on the history of the library of Baumgartenberg.

15 For more detailed information on the number of surviving books from each monastery see section 3.

16 For more details on possible exchange processes and how to determine them see Kaska, "Schreiber und Werk"; and Haidinger and Lackner, *Bibliothek.* While only scribal networks are discussed in this paper, the investigation is part of a larger project on the interaction between paleographical and philological networks in twelfth-century book production with a focus on the library of Baumgartenberg. For a short description, see: http://www.iter-austriacum.at/kodikologie/texttransfer-und-buchaustausch-netzwerke-monastischer-handschriftenproduktion-am-beispiel-des-zisterzienserstifts-baumgartenberg-in-oberoesterreich/ (accessed May 25, 2022).

2. Available data and processing

For my study, I use paleographical data from two different sources: most information comes from an online publication by Alois Haidinger, while additional material is provided by my own research on the library and scriptorium of Baumgartenberg.[17]

In 2010, Alois Haidinger and Franz Lackner started to catalogue the medieval manuscripts in Heiligenkreuz. In addition to detailed descriptions of manuscript content and codicological features,[18] considerable effort was put into identifying all the scribes, rubricators and correctors. The results of this detailed paleographical analysis have been continuously published online at www.scriptoria.at since 2013 (see figure 1). A short analysis of the early scriptorium was also published in printed form in 2015.[19]

In recent years, the scope of Haidinger's research has expanded to other monasteries whose manuscripts can be connected to the Heiligenkreuz scriptorium. Intensive work has gone into analyzing the early scriptorium of Zwettl. To a lesser extent, data on twelfth-century manuscripts from the Cistercian monastery of Rein, and on a few manuscripts from Baumgartenberg that are today in the Austrian National Library,[20] is also available online. In a future update, scriptoria.at will also include an analysis of the illuminations in all manuscripts.[21]

The basic unit of reference for the paleographical analysis is not manuscripts but codicological units. Manuscripts can consist of one or more codicological units, potentially copied at different times periods or in different production contexts. Multiple units were sometimes combined into one manuscript shortly after

17 On how to identify scriptoria in the high Middle Ages see Garand, "Manuscrits monastiques"; Egger, "Suche," 377–88. On the practical aspects of scriptorium research see e.g., the discussions in Cohen-Mushlin, *A Medieval Scriptorium,* 53–55; Golob, *Cistercian Manuscripts,* 64–68.

18 The earliest manuscripts are published in Haidinger and Lackner, *Bibliothek.* Further manuscript descriptions can be found at: https://www.scriptoria.at/cgi-bin/sc_desc.php (accessed May 25, 2022).

19 Haidinger and Lackner, *Bibliothek,* 21–35.

20 The data is not always complete and was reevaluated and expanded by my own studies.

21 See the announcement on the website scriptoria.at: "Eine wesentlich erweiterte Version von scriptoria.at wird in der ersten Jahreshälfte 2022 online gestellt werden. Zu jeder Schreiberhand sollen nicht nur wie bisher Schriftspecimina in Form von Abbildungen, sondern zusätzlich sukzessive Zusammenstellungen ihrer Schriftcharakteristika in Form von Abbildungen von Kürzungen, Ligaturen, Einzelbuchstaben und Wörtern beziehungsweise Wortteilenwerden geboten werden. Darüber hinaus wird zu jeder in scriptoria.at genannten Handschrift auch deren Buchschmuck (einschließlich der niederrangigen Elemente wie Majuskelinitialen und Lombarden) analysiert werden." (accessed May 25, 2022).

Fig. 1 Screenshot of paleographical data for Heiligenkreuz Cod. 24 as presented in scriptoria.at

their production, but may also have been combined only centuries later when books were rebound. If the difference between their times of production is immediately obvious, e.g., in the case of a high medieval codicological unit bound together with late medieval codicological units, this is acknowledged even in the most basic manuscript catalogues. Many of the manuscripts investigated in this study, however, seem quite uniform at first glance. All pages were copied at approximately the same time, and sometimes even by the same scribes. Even in these manuscripts it is possible to differentiate between codicological units by comparing the quire marks and the ruling, or by investigating the quire structure. Some of these manuscripts have not changed their composition since their time of production, as can be shown by comparisons with medieval book lists. They might indeed have been planned that way and only copied in several codicological units for practical reasons. Others had parts added to them at a slightly later period. Since in many cases the date of compilation cannot be decided with certainty, the codicological unit remains the best reference unit for research.[22]

22 For an extensive discussion of the issue of codicological units on a more general level see Andrist et al., *La syntaxe*. For the monasteries discussed in this paper, the rearrangement of codicological units is obvious if medieval book lists and modern manuscript catalogues are compared. For Heiligenkreuz see the discussion of this topic throughout Kaska, "Untersuchungen."

In scriptoria.at, scribal hands are identified by letters and can be referenced using the shelfmark, for example "Heiligenkreuz Cod. 19 Hand A".[23] If a scribe can be identified in more than one codicological unit, it is named after an important manuscript in his oeuvre in a similar fashion, e.g., scribe "HLK 19 A". In a few cases the actual name of the scribe is known, such as Udalricus or Heinricus. These two types of identification are then used whenever a scribe appears in a codicological unit.

For each scribal hand, detailed information on its contribution to a manuscript is available on the website, which makes it possible to display the sequence of hands in the codicological unit (tab "Schreiber-Abfolge" on scriptoria.at). Similarly, all correctors and rubricators are identified and labeled, e.g., "Heiligenkreuz Cod. 19 Korrektor/Rubrikator A", with their contributions listed.

In my own project, I collected paleographical data on all manuscripts from Baumgartenberg mentioned in the thirteenth-century book list and labeled it according to Haidinger's convention. The data is stored locally in tabular form.

Scriptoria.at already provides a basic analysis of the paleographical data. For each scribe, all codicological units to which he contributed, as well as his role in these manuscripts – text scribe, corrector, rubricator – are listed and given a first impression of his importance within the scriptorium. In a separate list, all hands that collaborated with the scribe in question within the same codicological unit are collected as a first step to constructing a network of scribes.[24] Both lists are useful for researchers with a more in-depth knowledge of the scriptorium, but can be overwhelming for non-experts. It therefore seemed reasonable to use network display as a tool for better visualization and further analysis.

To investigate the relation between the scriptoria of motherhouses, daughterhouses and sisterhouses, I retrieved all published data on twelfth-century manuscripts[25] from Heiligenkreuz, Zwettl and Baumgartenberg from scriptoria.at by manually transferring it into tabular form (Excel sheet). The cut-off point of 1200 was chosen, as for Zwettl no sufficient data for the thirteenth-century scriptorium is available, and my own research on Baumgartenberg mainly focuses on the earliest manuscripts. The network therefore excludes data on the later development of the Heiligenkreuz scriptorium that is already available on scriptoria.at, as well as data on some early thirteenth-century Baumgartenberg manuscripts. Manuscript fragments were also not included, even if they can be dated to the twelfth

23 For a description of the naming system and the database in general see Haidinger and Lackner, *Bibliothek,* 21–22.

24 For the example of HLK 19 A, see the entry at: https://www.scriptoria.at/cgi-bin/rel_scribes.php?scribe_name=HLK%2019%20A (accessed May 25, 2022).

25 This includes manuscripts dated "um 1200" in the database.

Shelf-mark	Provenance	Date	Role	Name	Identification	Pages	Details
OÖLB Cod. 328	Baumgartenberg	1142–1175	text scribe	OOeLB 328 A	HLK 19 A	100	26ra–76va Z 8 (est); ...

Tab. 1 Basic data structure.

century. Some of them were written by known scribes, but since in general they lack information on scribal collaboration, they could distort the network.

The scriptoria.at data was then structured by using the "text to column" command in Excel. For the table, I followed the conventions on scriptoria.at and used the categories shelfmark, provenance, date, role of scribe, name of scribe, identification of scribe, pages and details (see Table 1). Nearly 1200 rows of data could thus be retrieved from Alois Haidinger's online publication. About 130 further rows were contributed by my own research, mainly on manuscripts in the State Library of Upper Austria.

Not all columns are relevant for the network analysis performed in this study; they were included in the original table to maintain a complete set of data from scriptoria.at for reference purposes and further studies.

The category "role" has the values text scribe, rubricator and corrector, and therefore indicates the type of contribution within the manuscript. Only text scribes were included in the analysis for this paper. Corrections to a manuscript can happen after the initial production and even after manuscripts were transferred from their place of origin; in fact, rubrics are not always entered immediately. Text scribes, on the other hand, are responsible for the very first step in copying a manuscript, i.e., copying the main part of the text from an exemplar.

In most codicological units, the "date" and "provenance" categories are solely based on recent paleographical observations.[26] This therefore provides a point of comparison for the results obtained by network analysis, but should not be used to construct a network. The category "pages" indicates the importance of the contribution of each scribe to a codicological unit.[27] and can be useful to differentiate

26 A Boolean category could be added for manuscripts/codicological units mentioned in the various booklists. This can narrow the date for manuscripts from Heiligenkreuz that are mentioned in the earliest book list and are therefore datable before the middle of the twelfth century.

27 "Details" adds a more detailed description of the parts of the manuscript each scribe wrote.

between different types of text scribes. Short contributions in many codicological units can, for instance, point towards "teachers" who write a few lines as exemplars for their pupils.[28] These categorizations require additional in-depth investigations of scribal features, which are not within the scope of this paper. For the basic network presented here, the page count was therefore not used in the analysis.

The main categories are thus "shelfmark" and "identification", which serve as the source and target for the edge table used for all network analyses. The shelfmark is the ID for a manuscript or codicological unit, while "identification" denotes the ID of a scribe who contributed to a particular codicological unit. If the scribe is known, i.e., he contributed to more than one codicological unit, the entry in the identification column follows the conventions detailed above. If a scribe cannot be identified in another codicological unit and the identification field would be empty, I used the "name" tag[29] with an additional hyphen for the identification column (in the example in Table 1 this would be OOeLB 328-A). This convention allows one to also include singular scribes in the network analysis, and helps to quickly differentiate known and unknown scribes.

For further processing, a reduced table was produced with information on all text scribes (target) in all codicological units (source) from Heiligenkreuz, Zwettl and Baumgartenberg before 1200. Additionally, a similar table that only features information on codicological units from the library of Heiligenkreuz was compiled in order to test the validity of the network projection as described in the following section.

Since the dataset lists contributions to codicological units by text scribes, the edges in this representation connect two different types of nodes: manuscript/codicological unit-nodes (category "shelfmark"), and scribe-nodes (category "identification"). It is therefore a two-mode network. The first, larger table contains 1103 edges and 935 nodes. Of these nodes, 365 are manuscripts, and 570 are scribes. The data for Heiligenkreuz alone contains 564 edges and 448 nodes (166 codicological unit nodes and 282 scribal nodes).

In a next step, both tables were imported into Gephi. Before analysis, the two-mode network needs to be transformed into two separate one-mode networks: a network with scribe-nodes that shows the connections (i.e., collaborations) between various scribes, and a network with codicological unit-nodes that brings

28 For a discussion of these "praescriptiones" in Carolingian scriptoria, see Tibbetts, "Praescriptiones."

29 The category "name" names the scribes as A, B, C, etc. as they appear in the manuscript without attempting to identify them (as discussed above).

together codicological units that share scribes. This was achieved by using the Gephi Plug-in MultiMode Networks Projections.

Different evaluation techniques were then applied to the network to obtain the following network properties:

Degree centrality

The parameter degree expresses the number of nodes to which a node is connected in a network. In this study, where nodes are scribes or codicological units, the degree expresses how well-connected certain scribes or codicological units are. In a network of codicological units, a node with a high degree indicates a codicological unit that shares scribes with many other codicological units. In the network of scribes, a node with a high degree indicates a scribe that worked together with many other scribes and is therefore highly connected within the scriptorium. However, the degree of a node is also increased if a scribe contributed to a codicological unit that many other scribes also contributed to. The degree value can therefore be high even if the scribe only contributed to a few codicological units, if these are multi-scribe codicological units. Since the number of pages each scribe wrote in each codicological unit is not included in this basic network model, the degree does not give an indication of the scribal output and therefore the scribe's importance for book production overall. The degree value is therefore a very basic tool of analysis, but has shown interesting results for the scriptorium of Heiligenkreuz. Nodes with a higher degree are larger in figure 3, which is the only graph where the degree is used for evaluation.

Betweenness Centrality

As a measure of centrality, "betweenness centrality" was chosen. This measures how often a node lies on the shortest path of connection between two points in the network. It therefore gives an indication of how important a node is to connect different parts of the network. In the scribal network, the betweenness centrality is especially high for scribes that work in more than one scriptorium. Each scriptorium forms its own cluster in the network that is connected by these scribes. Nodes with higher betweenness centrality are larger in the graph.

Clusters

A cluster is a group of nodes that is more densely connected to each other than to other nodes. In this study, these are either groups of codicological units that share the same scribes or groups of scribes who collaborate in several codicological units. To divide the network into clusters, the modularity of the graph is calculated in Gephi. Nodes belonging to the same clusters are given the same color. A major issue with modularity is its resolution limit. Some of the clusters identified by modularity optimization, such as those used by Gephi, might actually be

combinations of smaller clusters.[30] Small clusters in large networks thus remain hidden. To obtain a complete partition of the network, the major clusters have to be reexamined to determine if they themselves contain clusters. However, for the investigations in this paper that focus on large clusters related to separate scriptoria, this issue seems to be negligible (see the results in section 4).

3. Data quality

As with all medieval sources, several issues with data quality need to be addressed before attempting an analysis. The main issues are the incompleteness of the data and the methodological challenges when using results from paleographical research.

Clearly, the data is not complete, since not all manuscripts have survived to the present day. As indicated in the introduction, for Heiligenkreuz the earliest book list from the middle of the twelfth century indicates a loss of about one third of non-liturgical books. The survival rate of liturgical books from this period is close to zero – only a few fragments are still extant. Overall, the losses of the very early products of the scriptorium are therefore clearly higher, but cannot be quantified due to a lack of information. The loss rate for the latter part of the twelfth century can only be extrapolated by using the fourteenth-century book list as a general guideline.[31] Again, about two thirds of non-liturgical books mentioned in the list have survived, which would point to a rather constant rate of loss. However, some uncertainties remain. The loss rate can depend on the text transmitted in the manuscripts, as was shown for liturgical manuscripts. Different periods of production in the scriptorium might focus on different types of text, which in turn influence the rate of loss. During the very early stages of the library, Heiligenkreuz mainly collected works by the Church Fathers such as Augustine, Jerome and Gregory the Great, but barely included modern theologians in its library.[32] This is even true for Bernard of Clairvaux (*ca.* 1090–1153), one of the most important Cistercian authors of the time. By the middle of the twelfth century, only his *Apologia* was available in Heiligenkreuz, although in the following decades several manuscripts of his works were copied. Similarly, only two texts by Hugh of St. Victor (*ca.* 1097–1141), another highly popular contemporary theologian, are mentioned in the book list,[33] but more works were

30 See the discussion in Fortunato and Barthélemy, "Resolution limit."

31 There is no indication that more than one library existed in Heiligenkreuz in the fourteenth century, i.e., almost all extant manuscripts can be identified in the book lists. It therefore gives a good indication of the books possessed by the monastery at this time. As stated previously, liturgical manuscripts are the exception. For the distribution of books throughout the monastery see e.g., Gottlieb, *Über mittelalterliche Bibliotheken,* 303–9.

32 For a similar development in Aldersbach (OCist) see Frioli, "Antichi manoscritti," 212–13.

33 Haidinger and Lackner, *Bibliothek,* 16.

copied shortly after its compilation. These works were either not deemed immediately necessary for monastic life or, being rather recent works, might only have become available for copying in the second half of the twelfth century. Overall, one can assume a slightly different acquisition profile for this later time period. Does this then indicate a difference in losses between the time period covered by the first book list and slightly later copies? Cross checking with the extensive fourteenth-century book list, the only other source of information for the medieval library, does not show a clear pattern. Most works by Augustine or Gregory the Great are still extant, while many of Jerome's work are missing. Of 11 manuscripts with works by Bernard of Clairvaux, three are missing today and similar numbers can be established for Hugh of St. Victor. One category where the losses seem to be higher than average are commentaries on books of the Bible. This also explains the higher rate of loss for Jerome, whose commentaries were a prominent part of the early library. These books might have been replaced by more modern works as the genre evolved. They are an example of different loss patterns for different types of text, which still need to be investigated in more detail.

Another reason for the loss of very early copies might have been manuscript quality. As the scriptorium becomes more experienced and better or more complete exemplars became available, older copies may have been discarded. Two such cases will be discussed in section 5.

While these factors clearly influence the completeness of the data and can distort the analysis, it is not easy to quantify their influence. Of even greater concern is the difference in survival rate between the monasteries. The rate of loss at Baumgartenberg, about 50%, is much higher than that of Heiligenkreuz, which is in turn possibly higher than that of Zwettl. According to scriptoria.at, about 160 codicological units from prior to 1200 survive from Heiligenkreuz, and about 170 from Zwettl, although not all of these can be attributed to the respective scriptoria. For Baumgartenberg, only 27 codicological units can be attributed to this time period. Due to a lower rate of survival, as well as a smaller library to begin with, Baumgartenberg therefore differs considerably from the other two monasteries in the absolute number of codicological units available for investigation.

Paleographical data furthermore differs from other forms of data due to its subjective nature. Discerning different scribes in a codicological unit, or identifying the same hand in various codicological units, is done by visual comparison. The outcome of this greatly depends on the ability of the paleographer to recognize scribal features. Results can be disputed and different paleographers can form different opinions on the same raw material, i.e., the same corpus of manuscripts. Alois Haidinger, who is responsible for most of the data used in this study, is an expert on twelfth-century handwriting, and thus far no doubts have been raised on his observations. For both Heiligenkreuz and Zwettl, about one

third of the scribes could be identified in only one codicological unit.[34] At least in the early phase of the Heiligenkreuz scriptorium, these isolated hands often only contributed a few lines to a codicological unit. Since having only a small sample makes a paleographical comparison more difficult, it is quite possible that the number of unique hands is in fact lower.[35] Until automated scribal identification is better established and proven to be superior to the traditional work of paleographers, this issue cannot be resolved.

For Baumgartenberg the situation is more challenging. Alois Haidinger did investigate a few Baumgartenberg manuscripts, nowadays kept in the Austrian National Library, but most data was provided by my own research. While identifying scribes within the Baumgartenberg corpus is no different from Haidinger's work on Heiligenkreuz and Zwettl, identifying connections between the scriptoria is to a certain extent affected by my previous research. As part of my master's thesis, I compiled lists of the Heiligenkreuz scribes in manuscripts mentioned in the earliest book list, in order to identify hitherto unknown Heiligenkreuz manuscripts in the Austrian National Library.[36] This knowledge helped me considerably in identifying these Heiligenkreuz scribes in early Baumgartenberg manuscripts, without consulting additional manuscripts or images. By contrast, for the latter part of the twelfth century, as well as for all manuscripts from Zwettl, identification is only possible by comparing scribal hands with the data available on scriptoria.at. However, the website does not provide any search options, or even lists of scribes that can be scrolled through. This means clicking through hundreds of manuscripts and thousands of images in the hope of finding matching scribes. It is therefore very likely that some connections between Baumgartenberg and other scriptoria were missed.

For Baumgartenberg, the incompleteness of data is most likely a more serious issue than for Heiligenkreuz and Zwettl, due to the nature of its early book production. Many of the early Baumgartenberg manuscripts are closely connected to the Heiligenkreuz scriptorium, i.e., they were at least partly written by prominent Heiligenkreuz scribes.[37] At the same time, there are not many scribes that can be identified in more than one Baumgartenberg manuscript but not in Heiligenkreuz. A number of manuscripts cannot be connected to other Baumgartenberg manuscripts at all. It therefore seems likely that until the latter part of the twelfth century, there was no productive, independent scriptorium in Baumgar-

34 This number was taken from the data available on scriptoria.at. For the early phase of the Heiligenkreuz scriptorium, Alois Haidinger reports similar numbers; see Haidinger and Lackner, *Bibliothek,* 28. Manuscripts that were clearly not written in the scriptorium were excluded. For imported manuscripts, see the filter "Entstehungsort" in scriptoria.at.

35 Haidinger and Lackner, *Bibliothek,* 28–29, especially n. 76.

36 Kaska, *Neu identifzierte.*

37 For more details and examples, see Kaska, *Schreiber und Werke*.

tenberg.[38] Manuscripts were produced in close collaboration with Heiligenkreuz and also transferred from the motherhouse.[39] Since philological investigations show close textual connections to Zwettl for several texts,[40] it seems reasonable to assume similar exchange processes for scribes that I have so far been unable to identify by paleographical comparisons. Overall, therefore, solely due to limitations in the data collection, the network will be more incomplete for Baumgartenberg than for Heiligenkreuz and Zwettl.

4. Network properties and analysis

After this more general introduction on data acquisition and quality, the following paragraphs will discuss several types of network diagrams obtained from the complete dataset, as well as data on individual scriptoria.

To compare the results from the traditional paleographical investigations discussed above with those obtained by network analysis, I started the investigation by looking solely at the scriptorium of Heiligenkreuz. For its early period, Alois Haidinger has already provided his interpretation of the paleographical data by dating the codicological units and naming important scribes. The early book list also allows the grouping of manuscripts based on external written evidence. For the first network diagram, therefore, only data on Heiligenkreuz manuscripts up to 1200 was included (figure 2). The nodes in this graph are codicological units that are connected via shared scribes (edges). The node size indicates the betweenness centrality, while the colors denote the clusters of codicological units obtained by calculating the modularity in Gephi.[41]

Overall, the graph contains 9 such clusters and 37 isolates, labeled in gray. These are paleographically isolated codicological units. Their scribes could not be identified in any other Heiligenkreuz manuscripts, and they thus appear as islands on the graph. A further two clusters only contain two codicological units each, while one clusters contains three. This indicates that they share scribes, but these scribes cannot be identified in any other manuscript in the main bulk of the network. Two of these clusters are most likely "artifacts" in the sense that they are dated to around 1200 and might be related to later manuscripts not included in the study. However, HLK Cod. 289, ÖNB Cod. 830 part 1 and HLK

38 The situation changes in the early thirteenth century, see Simader, "Österreich," 346–48 for details on the development of book illumination in Baumgartenberg.

39 One example is ÖNB Cod. 726. For another possible example see section 5.

40 Research is still ongoing. For one example see Kaska, "Zur hochmittelalterlichen Überlieferung."

41 The resolution was kept at the default value of 1 and the edge weight was taken into account, which lead to a modularity of 0.399. The distance is a result of the layout algorithm (Force Atlas).

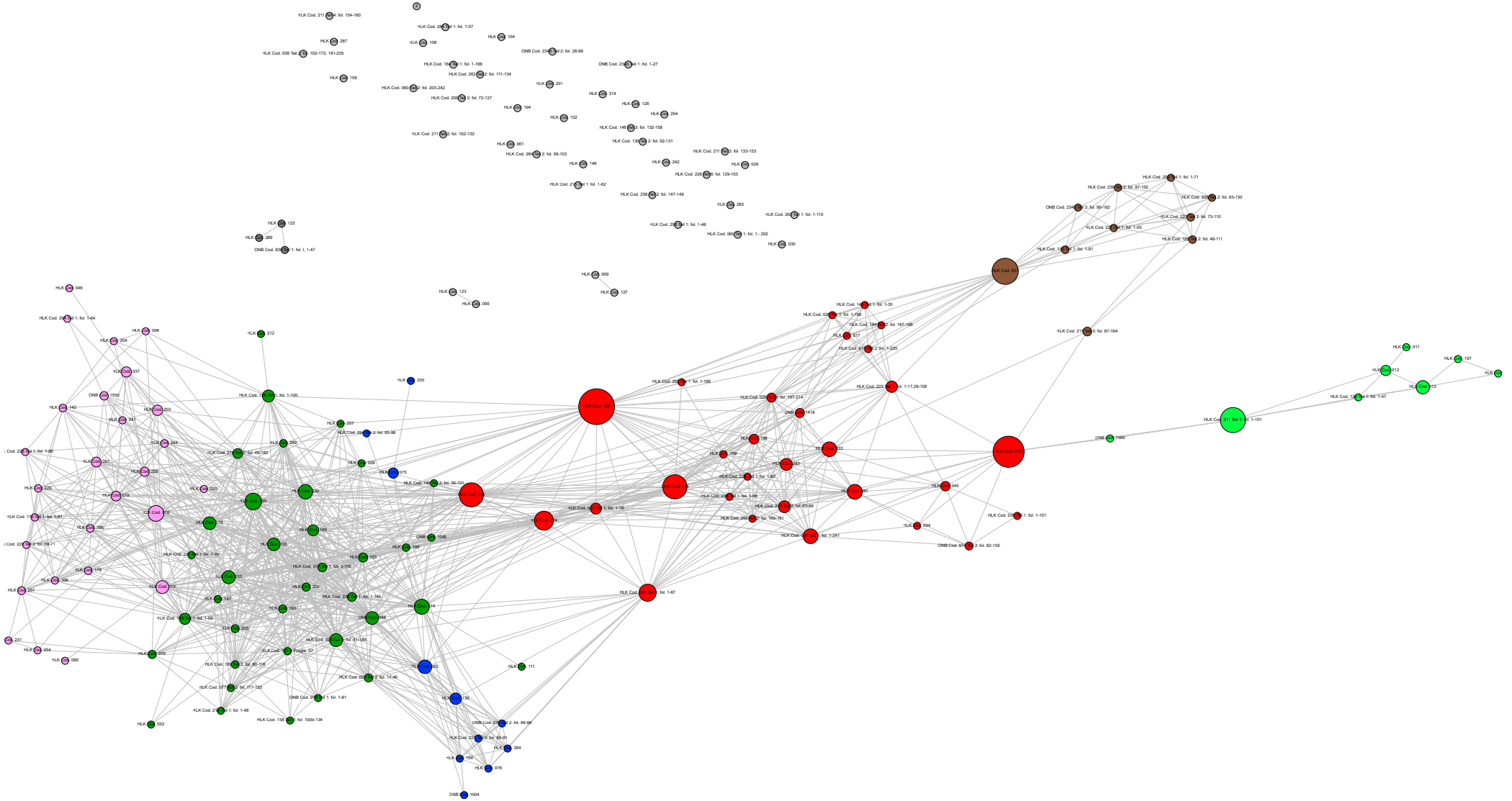

Fig. 2 Network of twelfth-century manuscripts from Heiligenkreuz (node size: betweenness centrality, colors: modularity)

eISSN: 2535-8863
DOI: 10.25517/jhnr.v9i1.192

Cod. 122, which form the third cluster, are mentioned in the earliest book list and would be expected to be part of the main bulk of the network. Closer inspection shows that all three manuscripts show scribal characteristics typical of manuscripts from France (Burgundy?). Nevertheless, they were most likely written in Heiligenkreuz, since scribe HLK 122 A copied the monastery's earliest extant charter.[42] They also share rubricators and correctors with other Heiligenkreuz manuscripts. Since these scribal roles were not included in the networks presented in this paper, they appear to have no connection to the main component of this graph.

This leaves six clusters (modularity classes) with between 8 and 37 elements each that constitute the main bulk of the network. A highly interconnected group forms the center (dark green). This is surrounded by slightly less interconnected groups (dark blue and pink). All three contain manuscripts mentioned in the earliest book list, as well as some not mentioned in the list. This doesn't come as a surprise, since there is no indication of the scriptorium stopping to produce manuscripts after the compilation of the book list. The book list is therefore a snapshot of a still-growing library, and many scribes continued their work into the third quarter of the twelfth century. Further paleographical investigation could help to determine if the division of the main component into three distinct groups can be related to the inner organization of the scriptorium, or any evolution in manuscript production. At this stage it would also be necessary to check the validity of the modularity algorithm, i.e., to determine if these clusters are constructed of smaller clusters and thus if they are hiding further communities (as discussed in the previous section).

A clear evolution can be observed in the clusters on the right-hand side of the graph. A large cluster (red) is dated to the third quarter of the twelfth century on scriptoria.at, and none of the manuscripts are mentioned in the book list. A few codicological units are dated to the middle of the twelfth century (e.g., HLK Cod. 224 or HLK Cod. 225 part 1: fol. 1–67). Considering their close association with slightly later codicological units in this network, a reevaluation of these dates might be necessary. To the far right of the diagram, a small group of codicological units (brown) is mainly connected to the scriptorium through Cod. 31. Also, for another group (light green), only one connection to other codicological units from Heiligenkreuz has so far been established (HLK Cod. 211 part 1). This is due to a single scribe active in this codicological unit (HLK 211 A) who also contributed to HLK Cod. 210, a manuscript highly connected within the large "light green cluster", as well as to ÖNB Cod. 1580. All manuscripts within the "light green cluster" are dated to the late twelfth century. These include the

42 Kaska, "Untersuchungen," 23–24. For French scribes in Heiligenkreuz, see Haidinger and Lackner, *Bibliothek,* 23–26.

so-called *Magnum Legendarium Austriacum* that will be discussed in more detail in section 5.

Overall, the network partition visualizes the development of the scriptorium over time, and shows that the Gephi modularity function does indeed provide reliable results at this level. There is a flush of activity in the early phase spanning from the foundation in 1133/4 to some point after the compilation of the book list (1147 at the latest). The scriptorium then enters – without a clear break – a new phase at some point in the third quarter of the twelfth century, where a new generation of scribes takes over (red). Towards the end of the century, two more distinctive groups can be distinguished that might be connected to later manuscripts not included in this study.

In his book on the early Heiligenkreuz scriptorium, Alois Haidinger identifies a list of the main scribes up to the third quarter of the twelfth century who also participated in the production of the manuscripts mentioned in the book list compiled before 1147. These scribes contributed a large number of pages to the manuscripts and are thus present in a large number of codicological units. In a scribal network where the number of copied pages is not taken into account, one parameter for the importance of a scribe for the scriptorium is the number of other scribes he collaborated with.[43] Figure 3 therefore shows a network of scribes where the size of the node is correlated with its degree. The largest nodes are the scribes Udalricus and Leonhardus, followed by Heinricus, HLK 19 A, HLK 10 A, HLK 230 A, HLK 202 A and HLK 23 C. The ranking is similar to the list published by Haidinger, even though it is based on a larger dataset and uses a different ranking parameter.[44] In the case of the Heiligenkreuz scriptorium, the interconnectedness of a scribe is therefore a good indication of his importance for the scriptorium.

Overall, for Heiligenkreuz all results from network analysis agree well with published databases from traditional paleographical investigations. This implies that the network analysis, and especially the algorithm used for network partition in this study, can indeed serve as a tool to investigate scriptoria where raw data is available but limited analyses have been published, as is the case for Zwettl or for the interaction between Heiligenkreuz, Baumgartenberg and Zwettl. The next step was therefore to include all manuscripts from Heiligenkreuz, Baumgartenberg and Zwettl up to 1200 (for which paleographical data was available) in a network of codicological units (figure 4).

43 The issue of multi-scribe manuscripts discussed in section 2 has to be kept in mind when using the degree parameter.

44 In Haidinger's table, only the number of codicological units to which the scribes contributed is taken into account.

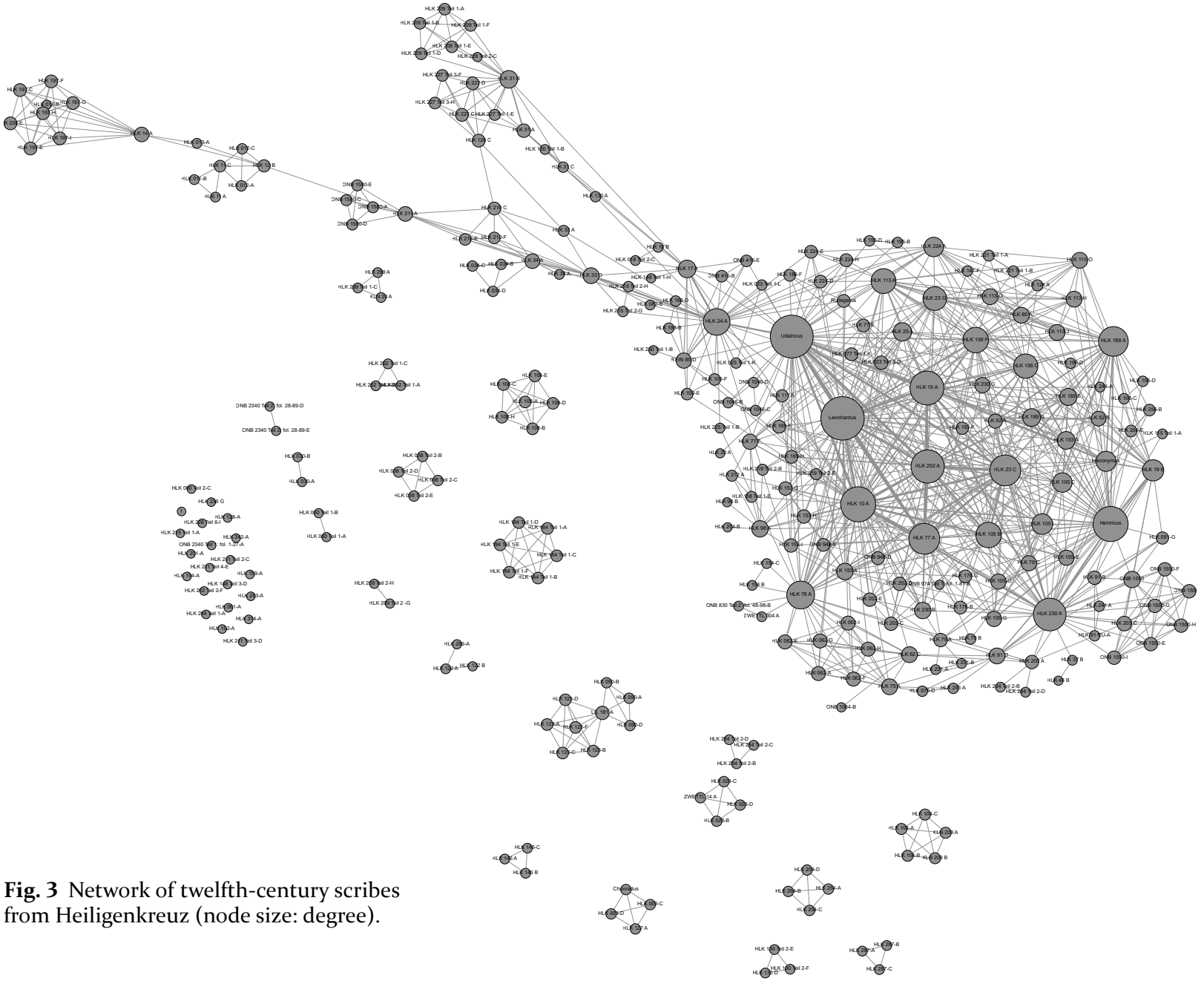

Fig. 3 Network of twelfth-century scribes from Heiligenkreuz (node size: degree).

eISSN: 2535-8863
DOI: 10.25517/jhnr.v9i1.192

The 365 nodes in this graph are codicological units, while the edges are shared scribes. There are eight interconnected clusters with seven to 79 elements each[45] that include 268 nodes in total. These larger clusters are represented by different colors in figure 4. The remaining nodes are part of very small clusters of two to three codicological units (16 nodes) or isolated codicological units[46] (grey in figure 4). 2182 edges connect these nodes.

The basic layout for the main component of the early Heiligenkreuz scriptorium (green) and its later development (red) is similar to the data that can be seen from Heiligenkreuz alone in figure 2. A small group of codicological units from Baumgartenberg is also part of the green cluster (e.g., OOeLB Cod. 318, OOeLB Cod. 328, OOeLB Cod. 319). This comes as no surprise, since several Heiligenkreuz scribes contributed to these codicological units. However, from additional scribal contributions as well as philological investigations it seems likely that they were in fact written in Baumgartenberg.[47] They are the result of a scribal exchange between motherhouses and daughterhouses that is not obvious from network analysis alone. A further small group of codicological units from Baumgartenberg at the bottom of the graph (light pink) is directly connected to the earlier phase of the Heiligenkreuz scriptorium.

Of particular interest are Heiligenkreuz's connections to Zwettl, which can be found in various groups. Zwettl Cod. 91 is an integral part of the earliest Heiligenkreuz group (green) and it is assumed that the manuscript was in fact written in Heiligenkreuz.[48] Considering the results for Baumgartenberg, this should be confirmed by philological or art historical analysis if possible.[49] The main bulk of the Zwettl scriptorium is correctly identified by the Gephi algorithm and represented by the blue group in the upper half of the graph. Attached to this group are further groups of codicological units from Zwettl, which are in turn connected to codicological units from Heiligenkreuz (brown, pink and yellow). There is a clear connection from the early Heiligenkreuz scriptorium (green) via a small group of codicological units (pink) to Zwettl. As will be shown in the scribal network, they share the scribe HLK 98 that worked for both scriptoria. A similar role is played by scribe HLK 203 A for the "brown group". The "pink group" is also connected through Zwettl Cod. 6 to another distinct group of the Zwettl scriptorium

45 For calculating the modularity the resolution was kept at the default value of 1 and the edge weight was taken into account, which lead to a modularity of 0.601. The distance is a result of the layout algorithm (Force Atlas).
46 For a discussion of these islands see previous paragraphs.
47 See in detail Kaska, "Schreiber und Werke."
48 See www.scriptoria.at under the shelfmark.
49 Zwettl Cod. 293 part 3 is also part of the same group. Only one scribe contributed to the manuscript (HLK 10 A), who worked on both Heiligenkreuz and Zwettl manuscripts, which makes any attribution less certain.

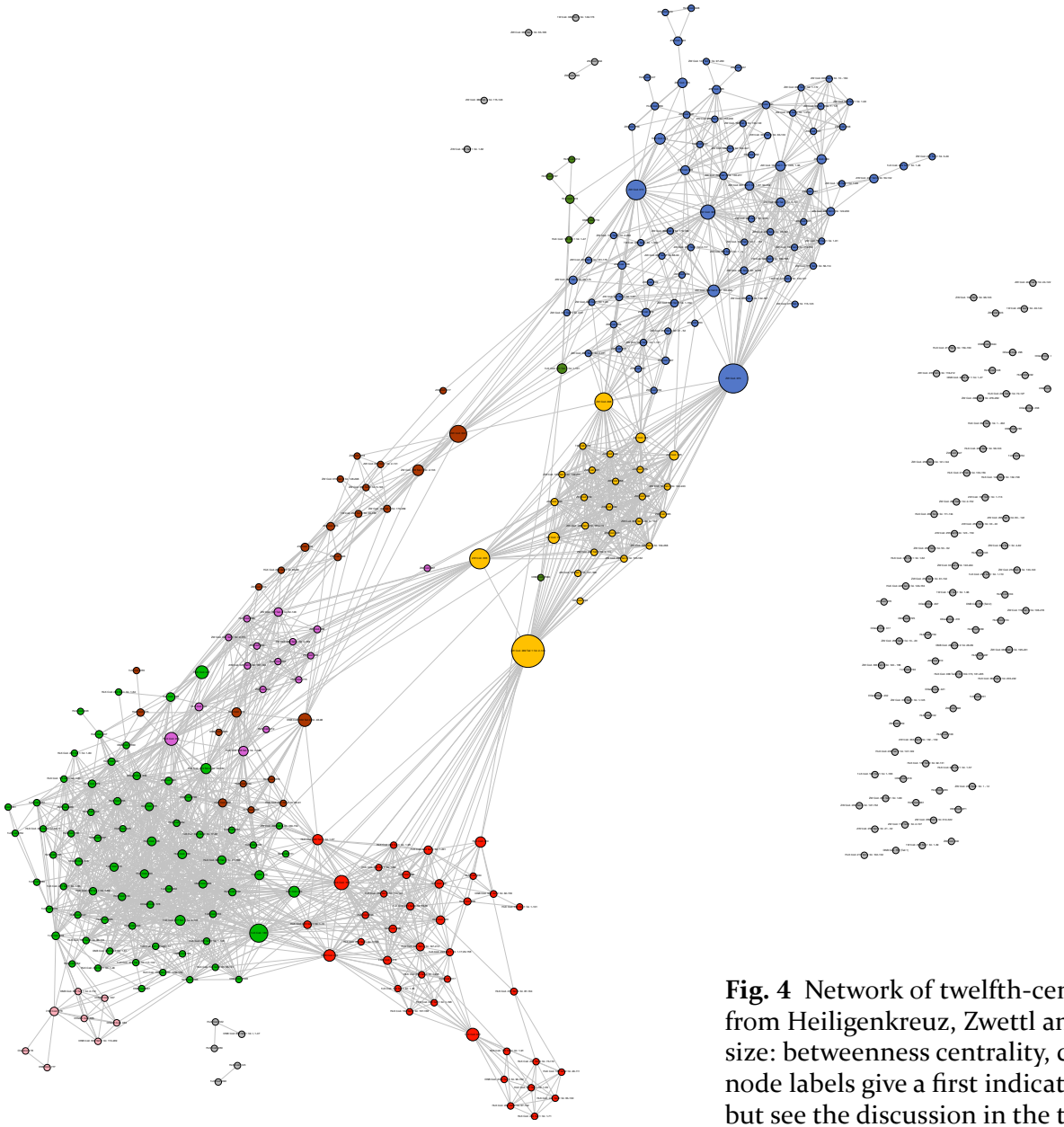

Fig. 4 Network of twelfth-century codicological units from Heiligenkreuz, Zwettl and Baumgartenberg (node size: betweenness centrality, colors: modularity). The node labels give a first indication of the place of origin, but see the discussion in the text.

eISSN: 2535-8863
DOI: 10.25517/jhnr.v9i1.192

(yellow). This group is in turn connected to the later Heiligenkreuz scriptorium (red) through the first part of Zwettl Cod. 299. This connection relies solely on the scribe HLK 24 A, one of the most prolific Heiligenkreuz scribes of that period. Apart from Cod. 299, he only contributed to one other codicological unit from the library of Zwettl, which may have been written in Heiligenkreuz (Cod. 295 part 1).[50] The connection between the later Heiligenkreuz and the Zwettl scriptorium is therefore quite weak. The network graph implies that there was more interaction between the motherhouse and the daughterhouse in the middle and perhaps the beginning of third quarter than towards the end of the twelfth century. This confirms recent investigations and manuscript datings and contradicts the assertion in older literature that book production in Zwettl only really started in the early 1170s.[51] It could also point towards a development of the Zwettl scriptorium over time towards greater independence. The results will have to be investigated in greater detail again and correlated with additional data and analyses of the manuscripts from Zwettl.

The most important change to the network by including Zwettl manuscripts occurs in the group around the *Magnum Legendarium Austriacum* (light green group in figure 2). In figure 4, some of these codicological units are part of a group (olive) that is closely connected to the Zwettl scriptorium (blue) in the upper part of the graph, but also has connections to Heiligenkreuz (e.g., Cod. 13 and 14).[52] Others even become part of the main group (blue) of the Zwettl scriptorium (e.g., HLK Cod. 11 and 12). This peculiarity will be discussed in more detail later.

A second option to learn about the interaction between the scriptoria is to look at the interaction of scribes instead of manuscripts/codicological units, i.e., to construct a network with scribe-nodes and edges that are codicological units from the complete data and then calculate the modularity for clustering (figure 5).[53] The number of nodes (570) is much larger than figure 4, which shows the network of codicological units, while the number of edges is lower (1819).

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50 See the list of HLK 24 A's contributions at: https://www.scriptoria.at/cgi-bin/rel_scribes.php?scribe_name=HLK%2024%20A (accessed May 25, 2022).

51 Rössl, "Schriftlichkeit."

52 A few other Heiligenkreuz manuscripts dated to the period around 1200 also moved to the outskirts of the Zwettl network. Here, the inclusion of thirteenth-century manuscripts might change the network properties. Also, Heiligenkreuz Cod. 299 part 1 is, in this representation, closely connected to the Zwettl scriptorium (on the edge of the blue group). However, the manuscript was actually written in the Augustinian monastery of Klosterneuburg and is only connected via one scribe from Klosterneuburg that also worked in Zwettl. It would be interesting to further investigate this interaction between the Cistercian scriptoria and the Augustinian house.

53 For calculating the modularity the resolution was kept at the default value of 1 and the edge weight was taken into account, which lead to a modularity of 0.683. The distance is a result of the layout algorithm (Force Atlas).

The large number of nodes corresponds to the large number of scribes that contributed to the codicological units (see discussion in section 3). Since in most cases we deal with multi-scribe manuscripts, it is not surprising that the number of communities detected in the data is also much higher than for the network of codicological units. Several scribes in one codicological unit already constitute a community in this representation. In total, 106 clusters were found, eleven of which include eight or more scribes. The largest cluster, which represents the early scriptorium of Heiligenkreuz, includes 96 scribes. All clusters with less than eight scribes were represented in grey in the graph. Many of these are isolated clusters, i.e., none of the scribes in a manuscript could be identified with known scribes from Heiligenkreuz, Zwettl or Baumgartenberg. They are arranged around the central part of the network in no particular order.

Both the scriptoria of Heiligenkreuz (bottom part with green and red main groups) and Zwettl (top with blue and purple main group) include several scribal communities with overlapping groups in the middle of the graph where scribes worked for both scriptoria. At the very bottom (brown), the scriptorium of Baumgartenberg is visible. These communities can give an insight into the inner workings of the scriptoria, highlighting which scribes regularly collaborated, and thus might also show a relative chronology of the scribes. Answering these questions in full would require a more in-depth investigation of the manuscripts and the addition of further data from rubrics and correctors, which is not within the scope of this study.

One parameter that can point towards exchange processes, however, can be easily determined. While in figure 2 the Heiligenkreuz scribes with the highest number of collaborations (highest degree) were highlighted, in figure 4 the most important scribes for connecting various part of the network, i.e., those with a high betweenness centrality, are visible. Higher betweenness centrality correlates with larger node size.

For the early Heiligenkreuz scriptorium (green) the largest nodes (and therefore the most important scribes) for network construction are: Udalricus, Heinricus and Leonardus, as well as the anonymous hands HLK 10 A and HLK 19 A. Udalricus and Heinricus are also among the most important scribes in the early phase of the scriptorium when it comes to the number of codicological units to which they contributed,[54] and have high degree values. This indicates that all three values can be useful for determining the importance of scribes within a scriptorium. In future analyses, this finding can be expanded to determine if a combination of these values can help to investigate the inner structure of the scriptorium.

54 Haidinger and Lackner, *Bibliothek,* 29.

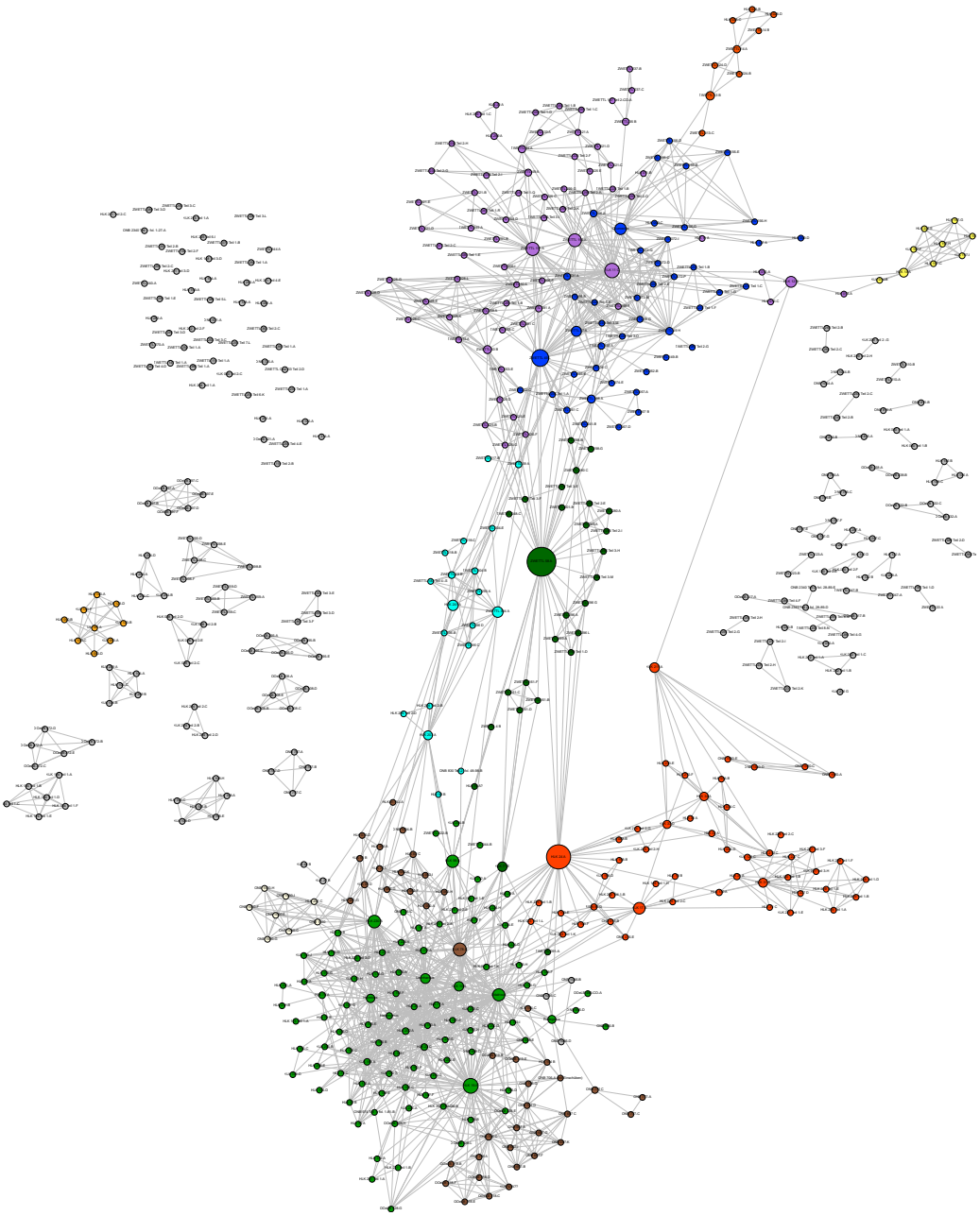

Fig. 5 Network of twelfth-century scribes from Heiligenkreuz, Zwettl and Baumgartenberg (node size: betweenness centrality, colors: clusters). The node labels give a first indication of the scribes' location, but see the discussion in the text.

From this network it appears that the most important connectors to the scriptorium of Baumgartenberg (brown group) are HLK 19 A and HLK 78 A. HLK 19 A contributes a few lines to several Baumgartenberg manuscripts, which might point towards a role as a manager or teacher.

For the later phase of the Heiligenkreuz scriptorium (red), the main connectors are HLK 24 A and HLK 17 A. HLK 17 A mainly connects to a group of scribes around HLK 31 B, while HLK 24, as discussed previously, brings together parts of the Heiligenkreuz scriptorium with Zwettl.

The turquoise group is even more closely connected to Zwettl than is obvious from the diagram. The scribes HLK 241 A and HLK 203 A actually contributed to fewer codicological units from Heiligenkreuz than from Zwettl. The main connector between the Heiligenkreuz main group (green) and this turquoise group is HLK 98 A, who contributed roughly equal numbers of codicological units to both scriptoria. Another large node in the intersection between Zwettl and Heiligenkreuz is ZWETTL 58 A as the center of the olive group. This scribe was already determined as a main scribe of the scriptorium in an older publication by Charlotte Ziegler.[55]

Other main members of the Zwettl scriptorium are found in the "blue group" as well as the "purple group". Central to this part of the network is ZWETTL 49 L, who is active in 19 codicological units as a text scribe. His importance to both the scriptorium and the network is even greater if one considers his contributions as a corrector and rubricator, which bring the number of his codicological units up to 49.[56] Further important connectors are Zwettl 77 A (blue), Zwettl 101 A (purple), and Zwettl 194 A (purple), who all contribute to several codicological units. Of similar importance is the scribe HLK 11 C (purple) named after HLK Cod. 11, one of four surviving volumes of the Heiligenkreuz *Magnum Legendarium Austriacum*.

5. Using the network

Using network analysis for paleographical data is different from many other applications of the technique in that considerable analytical work is needed to acquire the data. By comparing dozens of manuscripts and even more scribal hands by traditional means, a paleographer usually gains deep insight into the inner working of a scriptorium, i.e., who were the most important scribes, which

55 Ziegler, *Zisterzienserstift Zwettl,* xvi.

56 See his profile at: https://www.scriptoria.at/cgi-bin/rel_scribes.php?scribe_name=ZWETTL%2049%20L (accessed May 25, 2022). He is the main corrector for the Zwettl scriptorium.

scribes worked together etc., even before compiling the data necessary for network analysis.[57] This is especially true if the data is compiled into a database – a necessary step if one is to compare many hundreds of manuscripts. The basic network analysis preformed in this study therefore did not yield striking new results, but rather visualizes information already available to the researcher.

The situation is quite different for the user of a paleographical database such as scriptoria.at. For the earliest Heiligenkreuz manuscripts, Alois Haidinger has published some of his findings in a reader-friendly printed form.[58] He focuses on French influence in Heiligenkreuz – a topic that the database cannot cover – as well as on some of the most important scribes of this period. A similar analysis will be published on the Zwettl scriptorium.[59] For later manuscripts as well as many of the other scribes, researchers are left to work with scriptoria.at, where information can only be accessed through lists of manuscript shelfmarks (see introduction). This is where a network diagram becomes useful, as it allows the reader to quickly work through a vast amount of data about scribes in an accessible visual form. It shows which manuscripts/codicological units or scribes are related and, in the case of Heiligenkreuz, even shows the development of the scriptorium over time. It can also visually confirm hypotheses on manuscript identification and dating, and even point out further areas of research, as the following examples will show.

For two items from the Heiligenkreuz book list, it is argued by paleographers and art historians that the entries in the book list cannot be identified with extant copies of the text in the monastery's library. These manuscripts are said to have been written later, replacing earlier copies. One such case is Hugh of St. Victor's *De sacramentis*. We possess a manuscript with this text, Heiligenkreuz Cod. 100, dated to the latter part of the twelfth century, while the copy mentioned in the book list must have been copied before the middle of the twelfth century.[60] It is possible that the earlier copy made at Heiligenkreuz was given to the library of its newly established daughterhouse of Baumgartenberg shortly after the book list was compiled and survives in the Oberösterreichische Landesbibliothek (State Library of Upper Austria) in Linz. OÖLB Cod. 319 was already part of the library of Baumgartenberg in the Middle Ages, but was mainly copied by scribes from Heiligenkreuz. It shows the same *lacunae* as Heiligenkreuz Cod. 100, which cannot be found in any other Austrian copy of the text.[61] Similarly, Augustine's *Confessiones* is mentioned in the Heiligenkreuz book list, but today only survives in a manuscript from the third quarter of the twelfth century (Heiligenkreuz

57 See section 2 and especially note 17 for how to do scriptorium research.
58 Haidinger and Lackner, *Bibliothek*.
59 Expected as a volume in the series *Codices manuscripti et impressi. Supplementum*.
60 Haidinger and Lackner, *Bibliothek,* 16, n. 25.
61 Kaska, "Schreiber und Werke," 78–83.

Cod. 24).[62] It may be a copy of the codex mentioned in the book list that did not survive.

Indeed, both Cod. 100 and Cod. 24 are part of a group (red in figure 4) that shows the Heiligenkreuz scriptorium after its initial phase of production, and clearly cannot have been part of the library in the middle of the twelfth century. In turn, OÖLB Cod. 319 is closely connected to the first phase of production in Heiligenkreuz and therefore might well be the lost Heiligenkreuz copy. Network analysis therefore confirms previous assumptions about book loss and transfer based on traditional paleographical and philological methods.

As mentioned previously, another paleographically interesting group of codicological units and scribes centers on the Heiligenkreuz copy of the so-called *Magnum Legendarium Austriacum* (MLA, Heiligenkreuz Cod. 11–14). Recent work by Diarmuid Ó Riain has given deeper insight into the compilation and distribution of this voluminous hagiographical collection.[63] The multi-volume legendary survives in late twelfth to early thirteenth-century copies of varying completeness in the Benedictine monasteries of Melk (Lower Austria) and Admont (Styria), the Cistercian monasteries of Heiligenkreuz, Zwettl and Lilienfeld (all Lower Austria), as well as the Augustinian house of St. Pölten[64] (Lower Austria).. A few fragments of yet another copy were recently found in the Benedictine monastery of Göttweig in Lower Austria.[65] Ó Riain proposes that the MLA was compiled in Admont, where a direct copy of this "Ur-MLA" still exists. For the other manuscripts, a single intermediary copy β is proposed that served as the exemplar for the Heiligenkreuz copy. From β, a lost copy γ derives that then serves as the exemplar for the manuscripts from Melk, St. Pölten and Zwettl (Cod. 13–15 and 24). According to Ó Riain, the copies from Heiligenkreuz and Zwettl are therefore not directly related.[66]

Paleographical investigation plays a lesser role in Ó Riain's publications and is only used for localizing and dating the manuscripts. However, it might be interesting to look at the scribes and their collaborators again in the future and gain a deeper insight into the role of the MLA within the scriptoria of Heiligenkreuz and Zwettl, as well as their collaboration. The network diagram (figure 4) firmly places Heiligenkreuz Cod. 11 and 12 in the Zwettl scriptorium, while Cod. 13 and Cod. 14 are part of a small group connecting the scriptoria of the motherhouse and the daughterhouse. Overall, using the data available on scriptoria.at at the

62 Haidinger and Lackner, *Bibliothek,* 12, n. 11.
63 Ó Riain, "Magnum Legendarium"; Ó Riain, "Neue Erkenntnisse." For a list of manuscripts see: http://mla.dingbat.at/ (accessed May 25, 2022).
64 Today kept in the Austrian National Library.
65 Ó Riain, "Neue Erkenntnisse," 3–6.
66 For the stemma, see Ó Riain, "Magnum Legendarium," 153 and 141.

point of the writing of this article, the scribes of the Heiligenkreuz MLA are more closely connected to Zwettl than to Heiligenkreuz. This is at odds with the art historical findings that see part of the initials in the Heiligenkreuz MLA indebted to a group of Heiligenkreuz manuscripts from the fourth quarter of the twelfth century, and therefore assume Heiligenkreuz as the place of production.[67] It is possible that Heiligenkreuz scribes simultaneously worked for both Heiligenkreuz and Zwettl as is most likely the case for Heiligenkreuz scribes working for Baumgartenberg in an earlier period. It is likewise possible that we can see a transfer of personnel with e.g., scribe HLK 11 C moving from Heiligenkreuz to Zwettl, or vice versa. For firm conclusions, the interaction between the MLA scribes and other scribes should be investigated in more detail and correlated with information on the illuminators and their work, not only in the MLA but also in the other manuscripts from the two scriptoria. While this intriguing connection between the Heiligenkreuz MLA and Zwettl is visible from the lists provided on scriptoria.at, network analysis shows the extent of this interaction at a glance.

Despite all the challenges in data acquisition and interpretation, network analysis for paleographical data provides a valuable additional tool for accessible data visualization, and thus helps to disseminate paleographical research to a wider audience. It can encourage researchers to reevaluate previous results and identify new research questions. The results in this study also point towards the possibility of further, more advanced network analyses to learn more about scribal collaborations and the organization of a scriptorium that cannot be easily investigated by traditional methods alone.

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67 See the short description by Susanne Rischpler at: http://mla.oeaw.ac.at/#/decorations (accessed May 25, 2022).

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