

Mapping Landscapes in Transformation

Multidisciplinary Methods for Historical Analysis

Edited by

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POSTFACE

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Digital Humanities and GIS for Chinese Architecture

A Methodological Experiment

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How can one use a non-architectural source to build a new history of architecture? The study makes use of a corpus of Chinese local gazetteers (*Difangzhi*, lit. ‘local history’) to take up the methodological challenge. The source comprises 3,999 volumes dating from the tenth to the twentieth centuries covering all the populated area of China, and has been facilitated with a digital infrastructure.

This chapter is structured as follows: Sections I and II question some unacknowledged fractures and bias in the established histories of Chinese architecture, and open the issues in context. In Sections III and IV, the chapter proposes a new strategic approach to Chinese architecture with original questions and hypothesis. Section V elucidates how the new data were extracted, particularly the methods used in this study for mining and processing large-scale data thanks to digital humanities and geographic information system (GIS). Sections VI and VII report a ground-breaking result on Chinese architecture with two arguments.

The chapter embodies five innovative aspects: (1) using non-architectural sources to build architectural history; (2) bridging the long divided histories of the ancient and modern architecture of China; (3) focusing on the often ignored aspects of materiality in Chinese architecture, especially the mineral building materials; (4) applying cutting-edge datasets and tools from digital humanities into architecture, and providing critical viewpoints for either field. (5) The findings support two original arguments I come up with, showing both continuity and transformation of Chinese architecture in the *longue durée* of centuries; novel questions were generated too. The article is an introductory report for the project entitled ‘Mineral Building Materials in China. Rediscovering Built Environments in the Large Datasets of *Difangzhi*, 10–20th Centuries.’

A fracture in the historiography of Chinese architecture

Scholarly studies on Chinese architecture¹ present a clear division between subjects of ancient and modern times. This generates a fracture if one looks into the considerable timberwork-led narratives about ancient Chinese architecture (Liang et al. 2001; Liu 2003: 3; Zhang and Guo 1985: 57-58; Pan 2009; Chang 2016; Fu and Steinhardt 2017) and the masonry- and concrete-led narratives about the modern types (Wang and Fujimori 1992; Zheng 1999; Lai et al. 2016). The situation has partially resulted from the ideas of Chinese architectural historians of the first generation, typically in Liang Si-Cheng's words from the 1930s: 'The Chinese builder never cultivate a real knowledge of brick and stone as primary structural media for ordinary use. ... Masonry structures, therefore, occupy a position in no sense comparable to that in European architecture' (Liang et al. 2001: 451-452).

Western masonry structure, however, became the earliest and primary construction method used in building novel, modern types of architecture in China from the mid-nineteenth century onwards. This fact has been explicitly shown in source materials and the most recent studies addressing China's move towards modern architecture (Shu 2018; Shu and Coomans 2020; Shu et al. 2017; Shu 2015a; Shu 2015b; Shu 2013; Shu, Van Balen and Elsen, 2018). The western masonry works were built of mostly certain sorts of building materials made from mineral substances — typically brick, tile, stone, lime, earth, and concrete in the language of architects and engineers. The modern construction was conducted nearly exclusively by Chinese workers and builders with appropriate supervision from new architects and engineers, either foreign or Chinese. How could the Chinese workers and builders who 'never cultivate a real knowledge of brick and stone as primary structural media for ordinary use' effectively adapt to and become skilled in western masonry systems built in brick, stone and binding material of all sorts? In other words, why did masonry structure (not steel structure, for instance) become the first and successful step when China moved to western models of construction, followed by concrete structure that can be considered as a second success in China's modern architecture history? There must be some issues unaddressed.

1. In this study 'architecture' covers all the technique aspects of construction in addition to aesthetic viewpoint. Activities include but are not limited to: infrastructure, foundations and substructures, hydraulic works, production and use of building materials. A reference is given to Vitruvius' *The Ten Books on Architecture* (Vitruvio and Barbaro 1567; Vitruvius et al. 1914).

An unreliable source for architecture

Questioning this fracture and bias between the histories of Chinese architecture, I explore sources that are not conventional for architectural study. The bigger aim is to experiment with cross-boundary methods and to generate novel (forms of) knowledge of architecture. Chinese local gazetteers (*Difangzhi* 地方志, lit. ‘local history’, LG in abbr.) have been consulted as the first step, since the whole corpus of this sort of source covers all the populated areas of China and a long-term period from the tenth to the twentieth centuries.

The reliability of *Difangzhi*, however, has often been suspected in terms of architectural study. It is a sort of documentation written and compiled by the local gentry and elite officials, who basically were literati and scholars, not construction practitioners. Records in *Difangzhi*, although when it comes with construction topics, are very different from technical and monographic literature. The latter is in expert language filled with practitioners’ jargon and they have been systematically studied by historians of Chinese architecture since the twentieth century, while the former is a compilers’ (re-)interpretation of events and activities, and often does not provide solid or reliable information about dates, forms or technique details that historians of architecture have mostly cared about. The historians’ scholarly concentration has remained too narrow in particular (often monumental) works, architects, typologies or architectonics to build the histories of Chinese architecture. What they found in fieldwork does not always match what was recorded in *Difangzhi*, or is even not mentioned in *Difangzhi* at all.

The account below from Wilma Fairbank represents the typical ways in which Chinese local gazetteers have been used since the first generation of Chinese architectural historians and their ideas about it—‘guidebooks’ yet ‘not necessarily reliable.’ One can read, too, the approaches historians of Chinese architecture adopted to collect information and build the history since the very beginning.

‘Before undertaking such expeditions, the Liangs learned to map out their routes on the basis of local gazetteers. These scholarly compilations of local history noted the ancient temples, pagodas, and other monuments in which each district took pride. But the dates were not necessarily reliable, and often buildings that sounded like treasures and inspired long side trips were discovered to have been drastically altered or demolished. Nevertheless, these guidebooks provided the means of surveying wide areas, eventually whole provinces, without missing whatever important structures had survived. Of course, certain individual discoveries resulted from pursuing rumours,

word-of-mouth suggestions, even obscure monuments praised in traditional folksongs. In the 1930s the field of Chinese architectural history was truly open to the excitement of unprecedented finds' (Liang, Fairbank and Liang 2001: 26).

Turning the unreliable to reliable: from material evidence to knowledge of architecture

Architectures have always been transformed, destroyed or reconstructed over time, regarding either form or material. The written *Difangzhi* records of architecture from earlier periods do not necessarily correspond with the architectural remains one found in the field in later times. This does not mean that the *Difangzhi* records are not reliable, since the material evidence might disappear or be transformed in one way or another. The continuity and consistency of *Difangzhi*, instead, have ensured the transmission, dissemination and inheritance of architectural knowledge through Chinese literati. In other words, *Difangzhi* is a solid source about the architectural knowledge of Chinese literati.

This study, therefore, distinguishes between material evidence of architecture and histories of architecture. It considers the textual data from *Difangzhi* a collective, autonomous corpus of codified knowledge linked to elite literati and scholars, and differentiates it from the embodied knowledge retrieved from field and laboratory work (observation and experiment), or directly from craftsmen, practitioners and experts, which historians of Chinese architecture mostly rely on. In this sense, *Difangzhi* becomes a primary source of the knowledge of architecture. The smaller aim is to uncover a hidden history of Chinese architecture and the relevant building materials used in the *longue durée*, as well as certain (if any) unknown historical structure(s) of material culture.

These questions prompt the inquiry: how about the relations between the traditional elite yet non-expert knowledge of architecture as far as recorded in *Difangzhi* and the modern specialised knowledge built up by modern historians and ended up in a scholarly discipline of Chinese architecture? Secondly, how did the historical structure evolve into the nineteenth and twentieth centuries when intensive changes happened? Did it represent a decisive factor for the onset of the way the modern forms, ideas, and practice emerged? And thirdly, how is the elite knowledge re-conceived and reused today?

Old source in new digital shapes

The recently developed digital-GIS infrastructures of *Difangzhi* provide possibilities to answer these questions. New tools have turned *Difangzhi* into an exceptional novel source.

A Chinese local gazetteer book (or *Difangzhi* book) was compiled for a particular prefecture or province defined by administrative boundaries. For the purpose of government, it contains information of all sorts that was considered significant to the local society under official administration of the prefecture or province. The contents, consistently structured by themes, cover local landscape, customs, products, construction activities and others. The source per se is remarkable in terms of its large spatio-temporal coverage and good continuity. It has been well studied and elucidated in recent publications in either the Chinese or the English language (Liu et al. 2010; Dennis 2015).

As far as I can see, contents related to architecture are largely and continuously recorded in *Difangzhi*. However they have not yet been studied in a systematic manner. Building materials often appear in the sections and context of construction such as city fortification, hydraulic works, schools, temples and tombs (建置, 城池, 關營, 學校類), material specialty and local expertise (物產, 實業類), and moral, societal or political achievement linked to local peoples and models (藝文類等), covering broad time and space. They as a whole form a collective mental map of Chinese literati in conceiving architecture.

About 8,000 volumes of *Difangzhi* survive today, physically dispersed. This study uses a subset of 3,999 volumes as source material (~50% of existing LGs), which have been turned into collated and digitalized datasets. The corpus of the 3999 volumes has been facilitated with a work-in-progress infrastructure developed by the Max Planck Institute for the History of Science in Berlin (MPIWG) — the Local Gazetteers Research Tools (LoGaRT). The study takes full advantage of it. Each local gazetteer book, including all of its contents, is associated with geographic coordinates that refer to the local administrative capital according to the administrative level the book covers. Generic metadata are available too, including book year, dynasty, reign period, administrative typology, author, book edition and edition year. LoGaRT serve full text mining and geographical analysis to aid the metadata. Functions within LoGaRT have been explained in recent publications (Chen et al. 2017; Chen 2016; Chen et al. 2016).²

2. About LoGaRT, see: <https://www.mpiwg-berlin.mpg.de/research/projects/logart-local-gazetteers-research-tools>.

The two attributes of time — ‘book year’ and ‘edition year’ — have different meanings. Book year represents the year a local gazetteer book was compiled, and edition year represents the year the book was (re)printed. Calculating the dataset of 3999 volumes with the R software, 3750 volumes (94%) have the same book year and edition year, which means they are first edition books; 249 volumes (6%) have different book year and edition year, which means they are reprints. The book year data are related to the Chinese literati who absorbed and recorded the practical knowledge of architecture while the edition year data are associated with the books that aided in circulating the knowledge through publication and replication. Both agencies favoured the dissemination of the architectural knowledge.

The corpus used in the study contains volumes dating from the tenth to the twentieth centuries. The early centuries are represented by only a few volumes. From ca.1450, the corpus exhibits remarkable growth in quantity, with drops in the reign periods (*Nianhao* 年號) that were politically weak or short. Breaking down the 3,999 source gazetteers by dynasty (*Chaodai* 朝代), 1% are from the three Tang (618-907), Song (960-1279) and Yuan (1279-1368) dynasties, 13% are from the Ming Dynasty (1368-1644), a majority 68% are from the Qing Dynasty (1644-1912), and 18% are from the period of the Republic of China (1912-49). Uneven distribution of gazetteers also appears in reign periods within a dynasty. For instance, the Jiajing (嘉靖 1522-66, 5%) and Wanli (萬曆 1573-1620, 4%) reigns within the Ming Dynasty, and the Kangxi (康熙 1662-1722, 13%), Qianlong (乾隆 1736-95, 17%), and Guangxu (光緒 1875-1908, 14%) reigns within the Qing Dynasty contain relatively more volumes of local gazetteers than other reign periods [Map 1].

Digital humanities and GIS can do more

What do recent digital humanities tell us and what do they not?

Recent digital humanities have dealt with methodological reflections concerning data extracting, processing, and reading in different quantitative scales and disciplinary contexts (Berry and Fagerjord 2017; Gold and Klein 2016; Moretti 2015; Jockers 2013; Moretti 2013; Burdick et al. 2012; Southall, Mostern and Berman 2011; Moretti 2000). Culturomics well represents the digital text-search approach (Koplenig 2017; Blevins 2014; Leetaru 2011; Michel et al. 2011). Historians of China studies, like most digital historians, have largely invested in digital mapping based on GIS, themes apart from architecture (Southall, Mostern and Berman

2016; Berman 2015; Southall, Mostern and Berman 2011; Bol 2007).³ Most recently, architectural historians have started to use digital methods too (Galletti 2017; Jaskot and Van der Graaff 2017), and their source materials remain in relatively small quantities compared to those in Culturometrics studies. These developments are all encouraging.

Looking into older disciplinary contexts, the new digital developments actually have connotations different from one another, though they are under the same umbrella of ‘digital methods’. Digital historians have experienced digital mapping as a ‘spatial turn’ (Robertson, 2016: 294) with increasing attention to space, while architectural historians seem more excited about the broader scales of sites that digital methods could generate. In part, this reflects the fact that architectural and urban historians have nearly always dealt with space-related topics and mapping has long been a basic tool and approach for research, not to mention other digital tools for 3D modelling and image analysis. In this very study of architecture, not only are the spatial dimensions (all the populated regions of China) untraditionally big, but the temporal scale (from the tenth to twentieth centuries) is also exceptionally long among extant studies of all the fields mentioned above. This *longue durée* approach raises new challenges in text mining first of all.

The Chinese language went through complex linguistic changes and variations from the tenth to the twentieth centuries and from one place to another. It depends on local dialects, habits and styles of writing in different social groups, generating generic linguistic features and phenomena like so called 古今字, 通假字, 異體字, 俗字, 異文. For instance, brick, as a type of building material, could be signified by various Chinese characters and phrases such as 磚, 埤, 甃, 陶磚, 陶埤, 陶甃, 磚石, 埤石, 甃石; they all appear in the LG text. The changing Chinese language generates more complex — and often ambiguous — instances. The LoGaRT, following a Culturometrics approach, uses key word(s) or phrase(s) to explore relevant contents. The text mining thus has to rest on precise yet fragmental words or phrases. Meanwhile, authors and compilers of *Difangzhi* often did not use technical terms or jargon belonging to the lexicon of practitioners and experts, but had a different vocabulary. Therefore, in order to extract appropriate new data, the first and key step is defining appropriate words and phrases for text mining.

3. For more platforms and infrastructures see: CHGIS: <https://sites.fas.harvard.edu/~chgis/>.
Electronic Cultural Atlas Initiative: <http://www.ecai.org/>. DocuSky: <http://docusky.org.tw/DocuSky/ds-01.home.html>.

Building materials is a focus of this study outside of recognised historical structures or themes that gave apparent shapes to the local gazetteers. New digital tools were intended to uncover invisible ideas and historical structures hidden in the text. For this, the study requires meaningful data pertinent to building material instead of searching general linguistic terms superficially linked to that. It must examine the associated meanings of all the hit results and remove irrelevant contents. By the time the research was conducted, computers were not yet able to read this high-level knowledge independently. LoGaRT-generated mappings are often too abstract. Further contextualisation and in-depth analysis are very necessary.

A hybrid methodology was thus adopted. The standpoint agreed with ‘digital history 1.5’ (Fridlund 2018). A loop-round, semi-automatic mode was developed for the text mining and data processing, given the detail below. Distant and close reading, macro- and micro-analysis, qualitative and quantitative, analytical and synthetic methods were all employed in an integrated manner. In reading the spatio-temporal distribution of the architectural knowledge, GIS mapping was used as a tool to process and analyse data, like the view of the Harvard CHGIS project (Bol 2007: 6).

A loop-round working flow

The loop-round method was designed in order to mine the text as comprehensively as possible. A preliminary keyword-based search shows that resulting hits came from highly diverse sections and contexts in LG books. Moreover, the linguistic complexity and potential of OCR (optical character recognition) errors make it impossible to conduct a simple, schematic data extraction. Therefore, instant disambiguation was conducted. LoGaRT, GIS and RegEx tools were used in combination to assist text mining. The text mining was organised by themes of mineral building material. Each keyword search was followed by immediate review and contextualisation, both textual and geographical, and the aim was to identify and disambiguate the computer-resulted hits. Each search was controlled within the quantitative scale of fewer than 10,000 pages, which made the workload of context review practical. Further aided by GIS tools, the resulting intermediate data were processed into refined data in appropriate forms. The loop-round manner especially helped to avoid filtering out alternative terms and phrases that might be pertinent to the topics (Fig. 1).

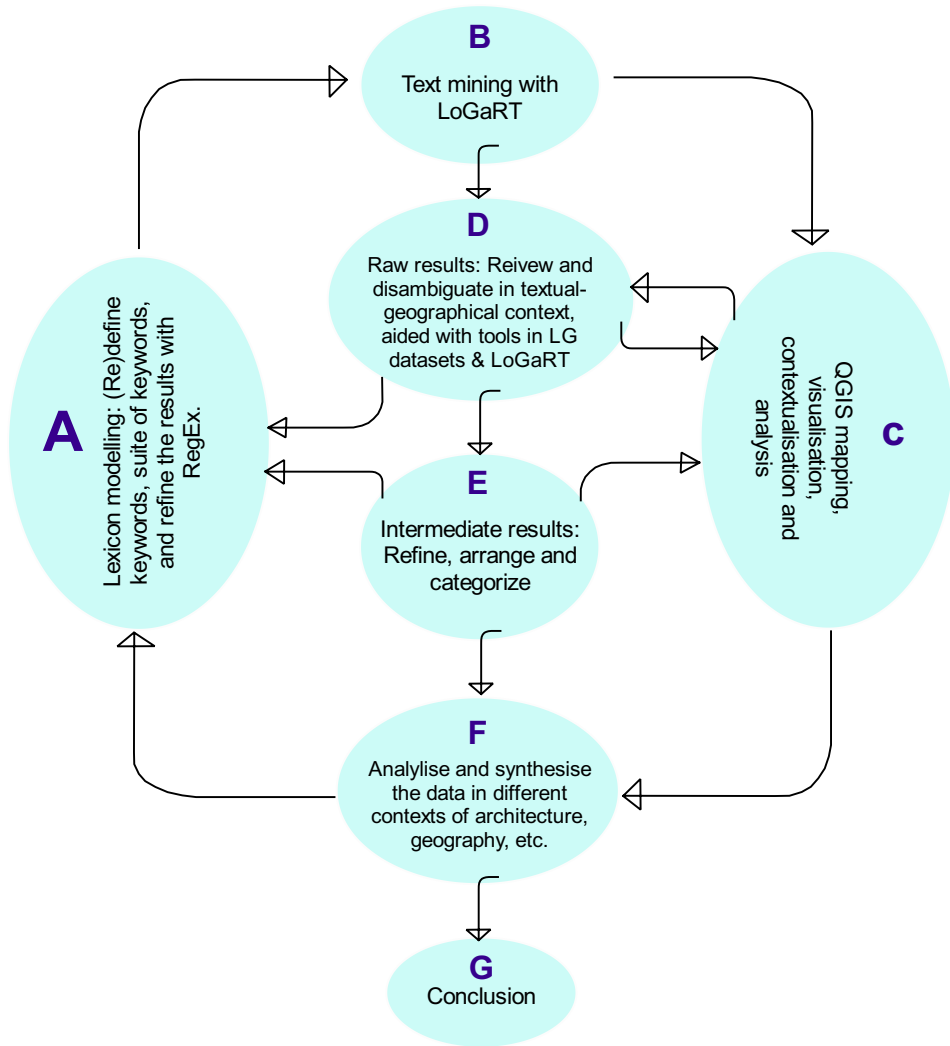


Fig. 1: The method: how the data were extracted from the Chinese local gazetteers.

Concerning the context that structured the Chinese local gazetteers, these two questions have always been taken into account: (1) In which sections did local gazetteer compilers place such information? (2) When and how did their descriptions vary — such as details, terminology, etc.? (Chen et al. 2017: 54). Answers to these questions may help us to understand circulation and evolution of the local knowledge.

Keywords modelling

Chinese keywords have been defined and modelled in the following steps:

1. Preparing a preliminary vocabulary from architectural literature, denoting the building materials used in China. The preliminary vocabulary was built on both architectonic terms from classic books of Chinese architecture and non-architectonic terms collated from non-expert sources (*Ying shan ling* 2006; Li 1103; Yun 1734; Dai 1755; Wang 2000; Wen 2008; Liu 2010; Fu, Steinhardt and Harrer 2017: 348-374). They cover the Chinese terms denoting brick, tile, stone, lime, natural earth and clay, traditional concrete (lime concrete), modern cement, and modern (reinforced) concrete, as well as the use of them in architecture.
2. Reshape the architectural terms within the LG text and context. The aim was to adapt the preliminary vocabulary into contextualised vocabulary for mining LG contents as efficiently as possible. This is because: (1) as mentioned earlier, the *Difangzhi* vocabulary of architecture is different from architectonic terms built by experts and practitioners, see examples below. (2) Presumably, the LG corpus contains potential textual patterns in the documentation of building materials, and recognising any textual patterns might help the text mining in one way or another.

In reshaping the preliminary vocabulary of architecture into an adapted vocabulary based on the *difangzhi* text, I conducted searching trials in the loop-round manner and repeatedly. Both simple (single) and advanced keyword modelling methods were used. Single keyword searching was followed by advanced keyword searching. Advanced keywords were modelled by using 'and' and 'or' combinations of sets of keywords (keyword suites), and search algorithms (RegEx) for keyword pattern defining. RegEx was efficient in detecting the potential textual pattern, refining searched results and remodelling keywords. Keywords and search algorithms were adjusted, remodelled, and combined on a case-by-case basis. In the end, a new vocabulary resulted, consisting of single keywords, keyword suites, and search algorithms that were adapted to the *Difangzhi* text.

The resulting vocabulary exhibited significant differences from the previous vocabulary based on architectural literature. For instance, in *Difangzhi*, artificially burnt brick and natural building stone were often customarily combined in one term as *zhuan-shi* (lit. brick-stone, with written variations in the Chinese character *zhuan*). The combination suggests that *Difangzhi* compilers and authors considered that brick and stone had very similar functions in construction.

Monographs of architecture, instead, consider them as two distinct sorts of material requiring different construction techniques from ancient to modern times. This distinction shows the abstract and collective features of the *Difangzhi* source. A similar example is *zhuan-wa* (lit. brick-tile, with written variations in *zhuan*), indicating that brick and roof tile shared similar methods of fabrication. Another example is 大木作 (*da-mu-zuo*), translated as ‘large-scale wooden structures’ (Fu, Steinhardt and Harrer 2017: 352). For historians of Chinese architecture, it was a basic term mostly used to denote the major and principal wooden structure of traditional Chinese architecture. In the corpus of LG, however simple keyword searching of 大木作 hit 19 results only with the book years covering a long period of 1482-1936. In contrast, keyword searching of “木樑 木梁” (*mu-liang*, lit. wooden beam) hit 989 results covering 1268-1949 [Map 2]. The close reading in context reveals that *mu-liang* often connotes the meaning of a horizontal timberwork system instead of individual beams. It is better translated as ‘wooden beam structure.’ Such examples clearly expose the different vocabularies between non-expert intellectuals and expert practitioners. Moreover, it should be kept in mind that the architectural terms in LG do not necessarily correspond to the terms or accurate meanings used by architectural experts, or the terms we use to categorise building materials today.

Table 1 shows some of the finally defined keywords and the architectural uses connoted or denoted by the keywords. Table 2 reports the resulting hit numbers of pertinent contents (measured by page), after checking each hit’s context through steps [A], [B], [C], and [D] as explained in the flowchart (Fig. 1).

Geographic analysis and comparative reading: adding-up and breaking-down

In the GIS mappings, point markers were always read together with provincial and prefectural administrative boundaries [Map 3b]. This is a compromise because of geographical uncertainty or just lack of precise data. The LoGaRT relates a local gazetteer book to point coordinates data (longitude and latitude) of its administrative capital, which is a ‘georeferenced location’ (Berman 2004). Thus not all the GIS points represent the precise places where the searched activities actually happened. Instead, a GIS point means that the knowledge of the activity once reached the marked place while the activity might happen in another place under the same administrative region (often) or even faraway (sometimes). Therefore, all the GIS points are considered as a reduced yet accurate spatial representations of knowledge, rather than precise locations of activity.

Functions in LoGART and QGIS infrastructure was utilised as the tool to analyse and process data. The purpose is to look for latent relations and patterns significant for the research questions. For instance, my text mining defined three major categories of stonework: ‘砌以石 building-in-stone’ (indicating the action), ‘石料 stone-material’ (the materiality), ‘石匠 stone-mason/-masonry’ (the labour) respectively (see the textual context in Tables 1 and 2). I examined and disambiguated the contents hit by these keywords, and input the intermediate results into QGIS. The ‘Histogram’ function in QGIS helped to visualise how the hit contents of stonework were distributed in timeline; longer and shorter breaks facilitated distant and close reading in comparison [Map 3a].

Meanwhile, the intermediate results were placed in classified layers by metadata such as book year, dynasty, reign period and administrative level. The data strata were added up in different combinations and/or broken down in varied divisions. For example, I added up the above mentioned three categories representing stonework, and then broke down the merged data by book year at equal intervals of 50 years. Each stratum of the 50-year data was overlaid cumulatively, so as to observe the step-by-step evolution in space [Map 3b]. Similar analyses were conducted within each category of ‘building-in-stone’, ‘stone-material’, and ‘stone-mason/-masonry’ [Map 4a and Map 4b]. The method successfully assisted in tracing geographical routes through which the knowledge was transmitted, developed and spread. Adding-up and breaking-down of data strata were always combined with comparative reading in a visual manner. These integrated methods proved to be powerful in my findings on Chinese architecture.

The advanced phase was to detect latent relationships between different building materials, construction activities, and the raw sources. Different thematic categories — such as ‘building-in-stone’, ‘replacing-wood-with-stone’, and ‘mineral mountain’ — were compared to one another with data strata in different combinations. Geographic context was always inspected, for building materials largely relied on geographical and geological resources. In the in-depth mapping, not only were political and cultural context introduced but also geographic and geological maps. Thanks to the vector mapping (and the vector format e-publication), large-scale distant reading and close reading are both feasible.

Relative frequency

The numbers of LG volumes appear quite uneven in different periods [Map 1]. This frames the quantitative scales of searchable data. In a defined category,

the more volumes of gazetteers, the more keyword-leading hits are inclined to be generated. Absolute numbers of hits are not sufficient for one to look up the changes in architecture. Therefore, an index 'I' was introduced to denote relative frequency of the records concerned. It is calculated by dividing the number of hit records in a statistical category by the total number of LG books in that category. For instance, in a thematic search of 'building-in-stone' (砌以石), the hits appear on 1,170 pages covering the period 1225-1949 (book year). Amongst them, two pages are from 23 books of the Song Dynasty, zero page from 11 books of the Yuan Dynasty, 149 pages from 510 books of the Ming Dynasty, 834 pages from 2,733 books of the Qing and 185 pages from 721 books of the Republic era; thus, the frequency value I of each dynasty is 8.7×10^{-2} (Song), 0 (Yuan), 29.2×10^{-2} (Ming), 30.5×10^{-2} (Qing) and 25.7×10^{-2} (Republic era), respectively. The records of 'building-in-stone' peak in the Qing dynasty in either absolute numbers or relative frequency. If breaking down the 1,170 hits by reign period, different I values of frequency will be generated, too. These parameters represent how frequent and intensive stone construction was recorded in LG in a particular dynasty or reign period. The diagram below represents the relative frequency of stonework as recorded in the local gazetteers, covering the results from 'building-in-stone', 'stone-material', and 'stone-mason/-masonry' cumulatively. It exhibits a sudden drop at the turn from the Ming to the Qing dynasty [Map 5a].

$I = NP/NB$

I: Index indicating the frequency of a thematic topic recorded in a defined category.

NP: number of pages hit by keyword-based text mining in the corpus of the defined category.

NB: total number of LG books in that category.

A discovery: replacing wood with stone and brick

This study opens a novel issue of 'replacing wooden structure with stone and brick' in ancient Chinese architecture, which earlier scholarship has not yet discussed.

I started text mining with keywords linked to timberwork. The purpose was to avoid ignoring wooden construction and prevent the isolation of this study of mineral building material. Surprisingly, the resulting contents are intensively concerned about the decay, deterioration, and collapse of wooden material and structure, and often telling of the fact that the timberwork was substituted by stone and/or brick masonry for better solidarity and greater durability. For instance, 34% results (119 out of 352) hit by the keyword for 'wooden column' (木柱) actually

talk about poor durability of the wooden structure and replacing wooden columns with stone and brick columns and walls. Similarly, in the contents hit by the keywords for ‘wooden-beam structure’ (木樑 木梁), about 30% (280+ out of 989) talk about replacing the wooden structure with stone masonry for similar reasons. Table 3 lists some representative examples with short textual context, and they are all direct quotations from the LG text.

Further extensive text mining extracted 3,493 pages (out of the 3,999 LG volumes) that contain records of the reconstruction and replacement of wooden structures with stone and brick materials, covering the period from 1201 to 1949. The records often appear in the context of building city walls and fortification, roads, schools, temples, bridges and other hydraulic works like ferry ports, culverts, banks, dykes and dams; they were arranged under the thematic section names of ‘Construction’, ‘Ferry and Bridge’, ‘Irrigation’, ‘Embankment and Weir’, ‘City and Fortification’, ‘School’, ‘Landscape and Geography’, and ‘Metal-Stone’ (Table 3). As in mapping, the records were mostly located along rivers [Map 7]. The highest quantity and frequency of the activities appear in the Qing dynasty (1644-1911), and it is in the Qing dynasty too that the widest and most intensive spatial distribution appears [Map 5b, Map 6, Map 8]. Jiangnan, a cultural-geographical region of East China, evidently maintained a mass of records throughout the Ming and Qing dynasties, covering Zhejiang, southern Jiangsu, the eastern and southern parts of Anhui and the northern part of Jiangxi provinces as shown in Map 7 and Map 8. In the Qing dynasty, breaking down the data by reign period and exhibiting them in a cumulative manner revealed the gradual growth and spread of the records in space [Map 8]. Through the analytical mappings [Map 8], it is clear that it was as early as during the Kangxi period (1662-1722) that the spatial structure of this replacing-wood-with-brick-and-stone activity took place.

The relative frequency, as represented in Map 5b, exhibits two high phases: one in the middle-Ming period covering 1465-1521 (成化, 弘治, 正德), which is surprising, and the other in the Qing periods covering 1796-1911. Neat increment appears in the Ming periods of 1522-1644 and throughout most periods of the Qing covering 1644-1875, yet with a disruptive fracture in between. The disruption may be explained as a consequence of the political revolution from the Ming to the Qing dynasty. The relative frequencies of the Song and Yuan dynasties are shown in hachures instead of bold bars because the LG books and the results from the Song (15 hits) and the Yuan (5 hits) are too few to be significant, comparing to the greater number of data in later periods. Concerning the relative frequency, the

trend of stonework is compatible with that of replacing wood with brick and stone [Maps 5a, 5b].

Opposite records of ‘replacing stone with wood’ were extensively searched too. In total 115 results were collated, which is many fewer than the 3,493 results of ‘replacing wood with stone’ in contrast (3% of the latter). The records of ‘replacing stone with wood’ cover a period of 1512-1949 in the Ming, Qing and Republic eras, and mostly are in the context of bridge construction, restoration and reconstruction. According to the records, bridges were repeatedly rebuilt in either stone or wood after serious damage, and stone was often the choice if conditions permitted. The reasons for changing from stone to wood can be cited as: (1) stone and its labour were too expensive while wood and its labour were relatively economical and more feasible; (2) interest in antique taste or ideological thoughts;⁴ and (3) stone blocks were recycled for another urgent project.⁵

New arguments and questions

The results reveal — accurately and to its fullest possible extent — firm evidence of a historical geography of Chinese architecture ‘replacing wood with brick and stone’. Architecturally, the material replacement meant that masonry structure developed widely in Ming and Qing China. The increasing use of brick in Ming and Qing China has been well recognised by Chinese architectural historians too (Liu 2003; Zhang and Guo 1985; Pan 2009), whose works rested on the synthesis of fieldwork instead.

The bigger picture the study reveals sustains two clear-cut arguments. One is to repair the earlier specified ‘fracture’ between ancient and modern Chinese architecture in the historiography. I argue that historical experiences of brick and stone masonry represent a decisive factor for the onset of the way China went on to develop modern architecture, in either ideas or practice, at a time when intensive changes happened in the nineteenth and twentieth centuries. I suggest keeping a

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4. “順治初太守李公正茂惟設木橋名曰利涉固有深意 康熙癸卯始易木為石以期久遠 議者謂形家言天門閉塞不利人文非自古設渡之意 復廢石橋易以木。” see: 江寧新志 (35137), 江蘇南京, 清乾隆, 1748, 卷第六 建置志, p. 354, and 江南通志 (16882), 江蘇, 清乾隆, 1796, 卷二十五 輿地志 關津一, p. 2775.
 5. “在城南明德都元時建木橋建屋於上後增以石明初因修城用石毀橋取石易以木今日久圯。” in 萬州志 (36814), 海南, 清道光, 1828, 卷四 建置 津梁, p. 288.

holistic sense of historical milieu in close reading tangible material evidence and writing histories of Chinese architecture no matter whether in ancient or modern times.

Secondly, I argue that the increasing trends of brick and stone in Ming and Qing influenced the wooden roofing construction of Chinese architecture at the same time. Chinese architecture was characterised by its large roofs with far-reaching, curved eaves, and this has been very well recognised. From middle to late Imperial China the large roof system (representatively Tang and Song architecture) transformed into a relatively smaller size and shorter eaves (representatively Qing architecture), accompanied by changes in construction techniques. Architectural historians have long studied the technique changes in all details, and considered the transformation a big issue in need of explanation (Lin 1932; Han 1988). Liu Zhi-Ping, probably for the first time in 1957, expressed the idea that the far-reaching eaves were used to help prevent earthen and wooden walls from deterioration caused by rain, and that the technical solution was later developed into aesthetic taste (Liu 2000: 58).⁶ Liu's idea has been quite well recognised by Chinese architectural historians. But very few scholarly studies have been undertaken to discuss the two points. Earthen structures are indeed sensitive to excessive moisture in all its forms—rain, standing water, snow, high and continual relative humidity (Avrami et al. 2008; Warren 1999; Alessandrini et al. 1990). Compared to earthen walls, brick and stone masonries were less vulnerable to moisture in general. Therefore, it is reasonable to say that the largely increased use of brick or stone in walling tended to promote the shrinking size of the wooden roof structure from middle to late Imperial China. The results of the study support such a hypothesis.

New questions are raised. Why was the activity of replacing wood with stone and brick so frequently recorded in mid-Ming periods of 1465-1521 (成化, 弘治, 正德) [Map 5b]? Why in the Qing dynasty was this architectural activity developed so widely in space and intensively in time with stable and continuous growth? What were the reasons? Did the trend of brick and stone form a new culture of architecture? What were the technical sources of the widespread masonry construction as recorded in *Difangzhi*? Liu (1985: 30) and Chang (1993) wrote about Islamic and Western influences in Imperial China's masonry works by studying

6. '中国建筑特点之一, 即是常用出檐结构. [...] 出檐大时雨水不易淋湿墙壁. 因为中国建筑多用版筑土墙或夹泥墙或木板墙, 墙角下很容易被雨水浸坏, 所以出檐是愈大愈好 [...] 因为大方方毫不掩饰, 毫不做作的出檐, 所以也就感觉出檐并不难看, 久而久之, 成了共同的习惯. 一般房屋如不出檐, 或檐短, 便觉得局促不美了.'

particular types of architecture and the architectonics. In addition to that, what other exterior sources and interior mechanism could result in the present discovery on such a large scale?

The source material the study relies on is far from complete. However this does not affect the critical phenomena it has exposed. In future, a more complete corpus of the Local Gazetteers would only add examples and details to the issue. The remaining research results about brick, stone, lime, earth and concrete, which has not yet been discussed in this article, will be discussed in a second article; the resultant lexicon in Tables 1 and 2 has cast a light over that.

Keyword-based text mining is a limited method. What lies outside the hit results is in need of further exploration and contextualisation. The loop-round searching mode and lexicon-defining method could be useful for digging up other sorts of Chinese sources, should the source be well collated into full text searchable datasets.

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Tables

Table 1: Keywords modelling for the text mining using LoGaRT.

No.	English Translation	Resulting lexicon used for text mining (different keywords are separated by comma)	Annotating the contents
[1]	Replacing wooden column with brick and stone	易木為石以期久遠，去木柱改砌以磚石，以石柱易木柱，以石易木柱，去木柱鼎建石竇，木柱有朽壞時後之人易之以石墩，去木柱改砌以磚石，舊用木柱且朽今易用石，星門舊以木柱元至正二年令麗思中易之以石，易捲蓬木柱以石易蓬以甌瓦，斷石以易木柱，易木柱以石，易木柱為石，木柱歲久易圯致煩屢修[···]鼎新重建易木以石可垂永久，以木柱易以磚柱，前後二殿俱五間七架易以石柱，重建木柱歲久仍頽雍正十二年奉部議估修以磚為柱，皆木柱官寺劉壽易之石，易木柱為石塚，斗門木柱易壞伐石代之，乾隆元年頭門燬本坊衆姓重修易木柱以石牆，昔之木柱悉易以石凡朽者更之，因木柱易朽易以石，大為拆改兩廡沿階木柱換用石柱襯瓦竹篔及周圍坵墻易之以磚，將向之木柱傾斜者轉而為石柱，···	<i>Mu-zhu</i> : Lit. wooden column. In the LG text it denotes the vertical load-bearing system transferring loads to the base in Chinese architecture.
[2]	Replacing wooden-beam or -column structure with stone	以石易木梁，九仙橋初名合沙橋舊為木梁宋景德間郡守袁逢吉始易以石，遂誓修石梁，舊為木梁國朝天順五年知府滿本愚易之以石，大洋橋初為木梁正統五年姚福德始易以石，永樂間重建木梁正統間改建石梁，國朝大順六年又重建陽春橋[···]正統三年巡撫侍郎周忱知縣項任改建石梁，通濟橋[···]初架木梁成化十年知府周正命民汪用本等募衆伐石券，易木梁以石，木梁易朽欲易以石，木柱有朽壞時後之人易之以石墩浮橋不如木柱之安木梁不如石敷之固而斷石之費比之豎木奚啻倍，···	<i>Mu-liang</i> : Lit. wooden beam. It means horizontal structural system consisting of wooden beams, transferring loads from top down to the vertical load-bearing system.

No.	English Translation	Resulting lexicon used for text mining (different keywords are separated by comma)	Annotating the contents
[3]	Replacing wood with brick and stone	易木為石, 易木以石, 改木為石, 易用石, 易之以石, 易以石, 易之石, 改砌以磚石, 易木梁以石, 石柱易木柱, 以石易木, 易捲蓬木柱以石, 石以易木, 易以石柱, 易木柱為石, 易木柱以石牆, 易木柱以石, 木柱換用石柱, 將向之木柱傾斜者轉而為石柱, 易木柱為石墩, 易殿柱以石, 改木柱為石墩, 易木柱為石墩, 木柱易壞伐石代之, 易木柱為石墩, 盡易木梁而石之, ...	The hit contents appear in the context of foundation, basement, stylobate, masonry wall, hydraulic work, arch, culvert, bridge, embankment, road pavement, etc. Reasons as told in the text: better solidarity and longer durability.
[4]	Reconstructing with brick and stone	易以磚石, 易以磚石, 易以甃石, 易之以磚石, 易之磚石, 用磚石重建, 甃石重甃, 益以磚石, 用磚石重築, 易為磚石, 加甃石重甃, 改用甃石重修, 以磚石改砌, 修葺易以磚石, ...	Reasons as told in the text: better solidarity and longer durability.
[5]	Replacing stone with wood	石亭易以木坊, 石梁易以木, 後易以木, 今易以木, 而易以木, 廢石而易以木, 廢石橋易以木, 石燬復易以木, 更易以木, 石橋易以木, 石梁燬者易以木, 易以木板, 圮易以木, 石圮易以木, 石燬易木, 石圮易木, 以木易石, ...	
[6]	Brick-tile	陶磚, 陶磚, 陶甃, 磚瓦, 磚瓦, 甃瓦	Uses in roof, wall, foundation, etc.
[7]	Brick-tile making place	磚窯, 磚窯, 甃窯, 磚瓦窯, 磚瓦窯, 甃瓦窯, 磚廠, 磚廠, 甃廠, 磚瓦廠, 磚瓦廠, 甃瓦廠, 甃瓦廠	Production of brick and tile
[8]	Brick-tile and the making	陶磚, 陶磚, 陶甃, 磚瓦, 磚瓦, 甃瓦, 磚窯, 磚窯, 甃窯, 磚瓦窯, 磚瓦窯, 甃瓦窯, 磚廠, 磚廠, 甃廠, 磚瓦廠, 磚瓦廠, 甃瓦廠, 甃瓦廠	Use and production of brick and tile, indicating all the relevant activities inclusively

No.	English Translation	Resulting lexicon used for text mining (different keywords are separated by comma)	Annotating the contents
[9]	Brick-stone	磚石, 埤石, 甃石	The LG records are mostly about:1) methods of construction; 2) reconstruction with stone and brick; 3) extraction, preparation, purchase and transportation of the materials.
[10]	Stone-mason/-masonry (the labor)	石匠	Labor of stone mason, or the works of stone masonry
[11]	Stone-material (the materiality)	石料	Material-based LG records, often related to the production, purchase, transportation and storage of stone materials in addition to its use.
[12]	Building-in-stone (the action)	砌以石 (補砌以石, 甃砌以石, 增砌以石, 包砌以石, 改砌以石, 築砌以石, etc.)	Uses of stone, emphasis on the action of building in stone
[13]	Stone works ([10]+[11]+[12])	砌以石, 石料, 石匠	All the hit contents related to stonework
[14]	Lime	石灰, 礦灰, 堊灰, 希灰, 石堊, 石堊燒, 石鍛, 鍛石, 鍛石, 煨石, 礦子灰, 白灰	
[15]	Lime-kiln	灰窰, 灰窯, 灰窰, 石灰窰, 石灰窯, 石灰窰	
[16]	Limestone-quarry	石灰山, 石灰嶺, 石灰陂, 石灰堆, 石灰礦, 灰礦	

No.	English Translation	Resulting lexicon used for text mining (different keywords are separated by comma)	Annotating the contents
[17]	Oyster-lime	蜃灰, 蠣灰, 蠣蚌灰, 蠣房, 古賁灰, 且炭亦灰	65% of the results (148 out of 229) were identified as contents speaking about using oyster-lime as binder. The rest is largely linked to food or medical uses.

Table 2: Crucial results hit by the keywords.

Category of keywords	Time span (book year based)	Counts of pages hit by keywords (irrelevant contents removed)						Most in the Section Names of
		Total	Song 960- 1279	Yuan 1279- 1368	Ming 1368- 1644	Qing 1644- 1912	Republic time 1912-49	
[1] Replacing wood column with brick and stone	1229-1949	119	1	0	10	94	14	藝文(or 文徵), 學校(or 學宮), 建置 (or 營建), 津梁(or 橋樑, 水利), 寺觀(or 壇廟), 金石, ...
[2] Replacing wooden-beam or column structure with stone	1229-1949	393	2	0	31	284	76	建置, 建設, 津梁, 學校, 營建, 城池, 藝文, 文徵, 輿地, 山川, 橋渡, 橋梁, 水利, ...
[3] Replacing wood with brick and stone	1201-1949	3493	15	5	384	2516	573	城池, 水利, 橋梁, 橋渡, 津梁, 建置, 地理考

Category of keywords	Time span (book year based)	Counts of pages hit by keywords (irrelevant contents removed)						Most in the Section Names of
		Total	Song 960- 1279	Yuan 1279- 1368	Ming 1368- 1644	Qing 1644- 1912	Republic time 1912-49	
[4] Reconstructing with brick and stone	1274-1949	288	1	1	43	200	43	建置: 城池, 橋樑, 閘壩, 堰塘, 壇廟, ...
[5] Replacing stone with wood		115	0	0	6	94	15	橋樑
[6] Brick-tile	1201-1949	2824	6	2	232	1576	1008	寺觀, 藝文志, 兵防, 城池, 建置, 城市, 關營, ... (highly diverse)
[7] Brick-tile making place	1464-1949	95	0	0	9	46	40	人物傳, 疆域志(橋樑, 村莊), 山川(水), 列傳, 實業
[8] Brick-tile and the making	1201-1949	2909	6	2	238	1621	1042	寺觀, 藝文, 兵防, 城池, 建置, 城市, 關營, ...
[9] Brick-stone	1201-1949	5502	10	6	714	3702	1070	城池, 水工, 城郭, 建置, ...
[10] Stone-mason/masonry (the labor)	1379-1949	1048	0	0	69	587	392	金石志
[11] Stone-material (the materiality)	1516-1949	465	0	0	15	252	198	建置, 海塘, ...

Category of keywords	Time span (book year based)	Counts of pages hit by keywords (irrelevant contents removed)						Most in the Section Names of
		Total	Song 960- 1279	Yuan 1279- 1368	Ming 1368- 1644	Qing 1644- 1912	Republic time 1912-49	
[12] Building-in-stone (the action)	1225-1949	1170	2	0	149	834	185	建置, 營建, 城池, 兵防, 水利, 橋樑, 橋渡, 漕運, 梁津, 古跡, ...
[13] Stone works (= [10]+ [11]+[12])	1225-1949	2683	2	0	233	1673	775	
[14] Lime	1068-1949	6007	14	7	367	3091	2528	地理考, 實業, 地質志, 物產, 輿地
[15] Lime-kiln	1455-1949	830	0	0	23	377	430	疆域, 物產, 礦產, 建置(or建設志), 城池, 關營(or關隘, 城堞考), 兵防(or 兵食), 山川, 輿地, 關梁, 河渠, ...
[16] Lime-stone-quarry	1265-1949	359	1	0	46	223	89	方輿, 山川, 輿地部, 疆域, ...
[17] Oyster-lime	1253-1949	229	1	2	21	150	55	建置, 田賦, 堤防, 物產

Table 3: Hit results of replacing wooden structure with brick and stone.

Hit by keywords	Time	under the Section Names of	Contents
木柱 (wooden column) 木樑 木梁 (wooden-beam structure)	1229-1949	建置, 建設, 營建 (construction); 津梁, 關梁, 橋樑, 橋渡 (ferry and bridge); 水利 (irrigation); 堤堰 (embankment and weir); 城池 (city and fortification); 學校 (school); 藝文, 文徵 (art and literature); 山川, 輿地 (landscape and geography); 金石 (records of metal and stone); etc. ...	30% of the hit results (393 out of 1325) are about replacing wood with stone
<p>Citing some examples in context (different quotations are divided by full stop):</p> <p>去木柱改砌以磚石。以石柱易木柱。以石易木柱。易木柱為石墩。木柱有朽壞時後之人易之以石墩。舊用木柱且朽今易用石。斲石以易木柱。易木柱以石。易木柱為石墩。舊用木柱者悉易以石。易殿柱以石。易木柱而結石壑。重建改木柱為石塚。易木柱為石塚。易木梁以石。盡易木梁而石之。木柱者水蠹浸剥易腐乃命石工購石砥柱悉以石。正德八年僉事李志剛去木柱改砌以磚石。重建長橋撤去木柱鼎建石竇六十二楹每竇用鐵鑼八條。星門舊以木柱元至正二年令龐思中易之以石。隆慶四年知縣黃一龍又總修之并易捲蓬木柱以石易蓬以甌瓦。木柱歲久易圯致煩屢修崇戊辰知縣楊之屏鼎新建易木以石可垂永久。以木柱易以磚柱。重建前後二殿俱五間七架易以石柱後殿始立。重建木柱歲久仍頽雍正十二年奉部議估修以磚為柱。樞星門向置木柱屢修屢圯甲寅夏公捐金創建石柱學宮煥然一新。創始皆木柱官寺劉壽易之石。樞星門一座明萬曆十九年知縣楊繼韶建久圯康熙二十年王基鞏重修奈木柱易朽雍正十二年邑原武罔訓導胡藝琦捐易以石。易木柱為石塚。東湖斗門木柱易壞伐石代之。乾隆元年頭門燬本坊衆姓重修易木柱以石牆。尊經閣木柱蟻蝕坍塌知縣姜山捐俸重建易以磚牆。昔之木柱悉易以石凡朽者更之毀者造之。因木柱易朽易以石。大為拆改兩廡沿階木柱換用石柱襯瓦竹篾及周圍坭牆易之以磚。將向之木柱傾斜者轉而為石柱。康熙二十六年知縣王廷諫重修聯兩廳為一中起高脊四十六年大殿木柱蟻蝕知縣吳廷芝易石柱。吳江有長橋[···]舊本木柱[···]元季易以石橋為洞門一百五處迄今二百餘年。迎恩橋[···]豎木為柱而架梁其上[···]柱有朽壞時後人易之以石墩[···]木梁不如石墩之固而斲石之費比之豎木奚啻百倍。重建前後二殿俱五間七架易以石柱。風雨之處舊用木柱今易以石柱可歷久弗壞也。改建木柱之梁以為石橋。先年俱用木柱[···]易圯三十年知縣陳朝策週圍易以磚砌。大興東湖水利以斗門木柱易壞伐石代之。撤去木柱仿照漕瀾橋之工咸易以石柱厚培堅築以期經久。殿中四木柱近座二年久蟻蛀民國二十三年甲戌改用石柱。···</p>			

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Maps

An introduction to the mapping section

This mapping section presents the study in a visual way, with detailed explanations of the source material, the methods, and the results. They can be considered as supplementary yet independent material for the textual sections. Maps 1-5a set out, step by step, the generic methods used for the study. Maps 5b, 6a, 6b, 7 and 8 deal with a critical phenomenon from the results. EXCEL, Spreadsheet, R, and QGIS were utilised to aid the LoGaRT in analysis and visualisation.

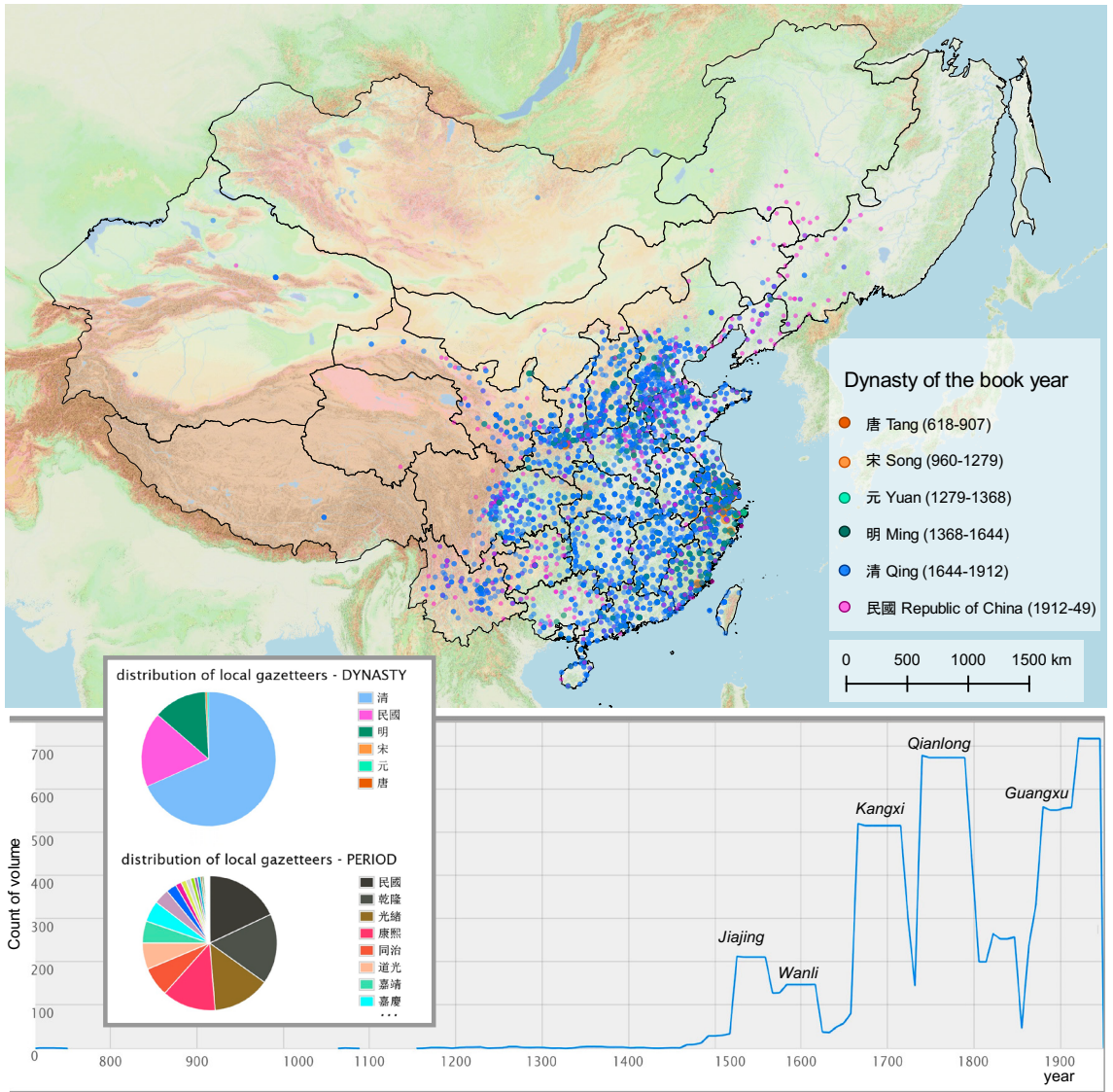
In visualisation, the 1820 administrative boundaries (CHGIS, 2016) were adopted consistently in favour of comparative reading. The factual territory and administrative boundaries of China were changing all the time. The study always contextualises the data with their contemporaneous administrative boundaries. Moreover, although 6% of the 3999 source books have different 'book year' and 'edition year' and the study has a concern in it, this section systematically adopts 'book year' data to establish the mapping analyses related to temporal processes, unless 'edition year' is specified like in Map 6b.

Map 1: Chang-Xue Shu (2018), *The Source: Spatio-Temporal Distribution of the 3999 Volumes of Chinese Local Gazetteers (Difangzhi)*.

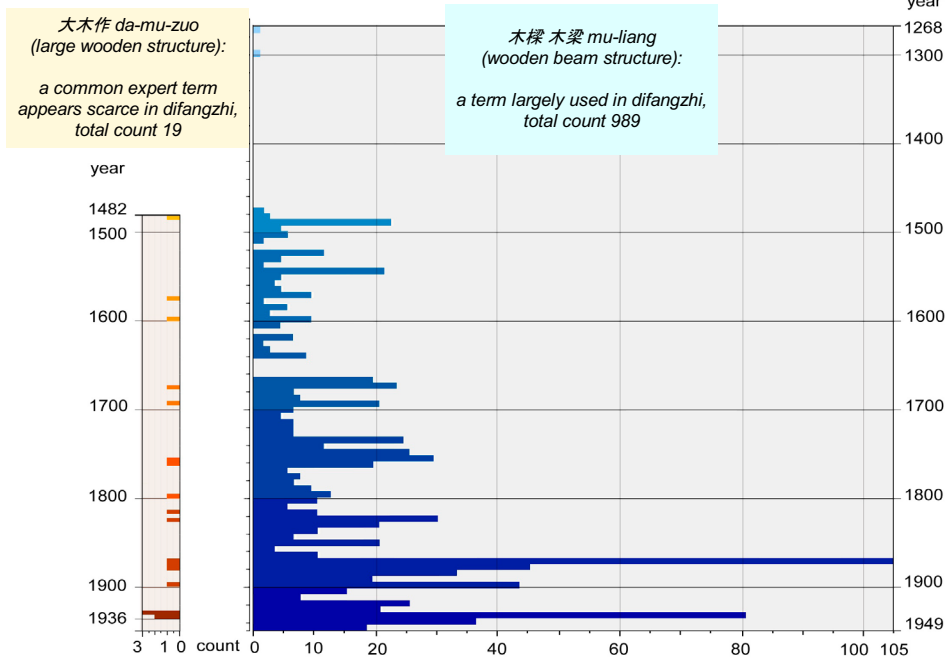
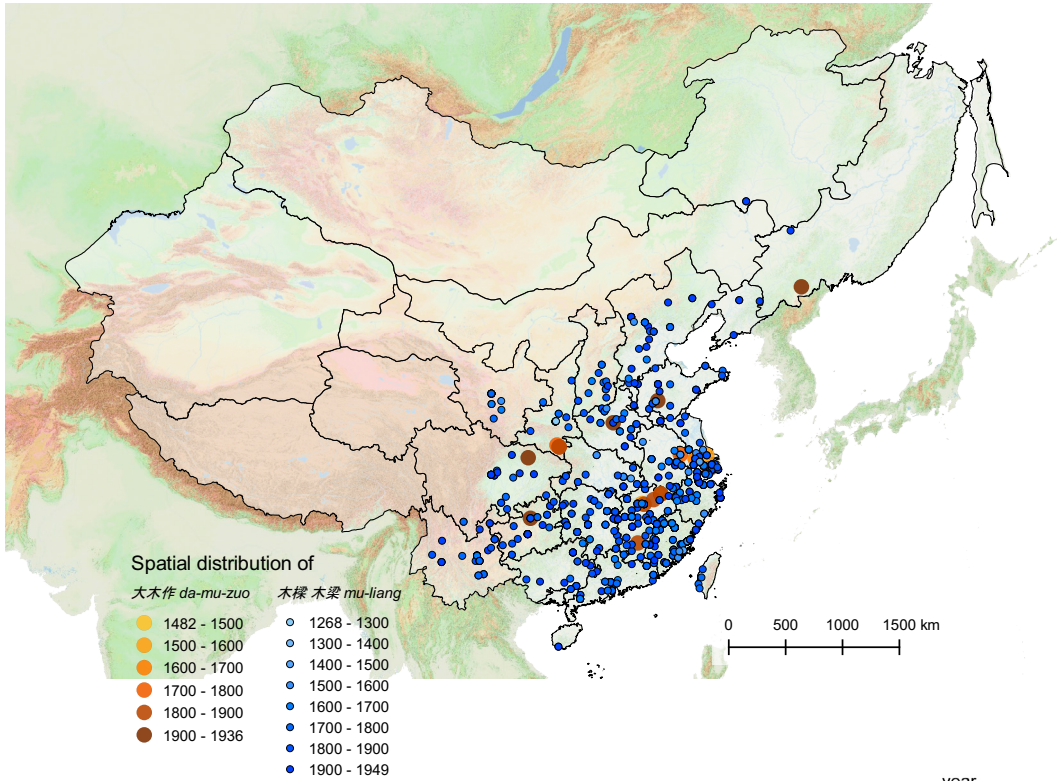
The map (top) shows that the source covers all the populated regions of China. The diagram and the pie charts (bottom) visualise a very uneven distribution of the local gazetteers in time. Although they cover the tenth to the twentieth centuries, the major part comes after the second half of the fifteenth century, that is, in Ming, Qing, and Republic times. It is obvious that politically stable and long reigns of Imperial China guaranteed that rising quantities of local gazetteers would be produced. This corresponds with the nature of *Difangzhi* — a sort of documentation written and compiled by the local gentry and elite officials, and it was closely related to local governing and administrative functions.

Map 2: Chang-Xue Shu (2018), *Starting with Keywords Modelling: Contrasting results of 'da-mu-zuo' and 'mu-liang', showing the Chinese local gazetteer has its vocabulary of architecture distinct from the experts'.*

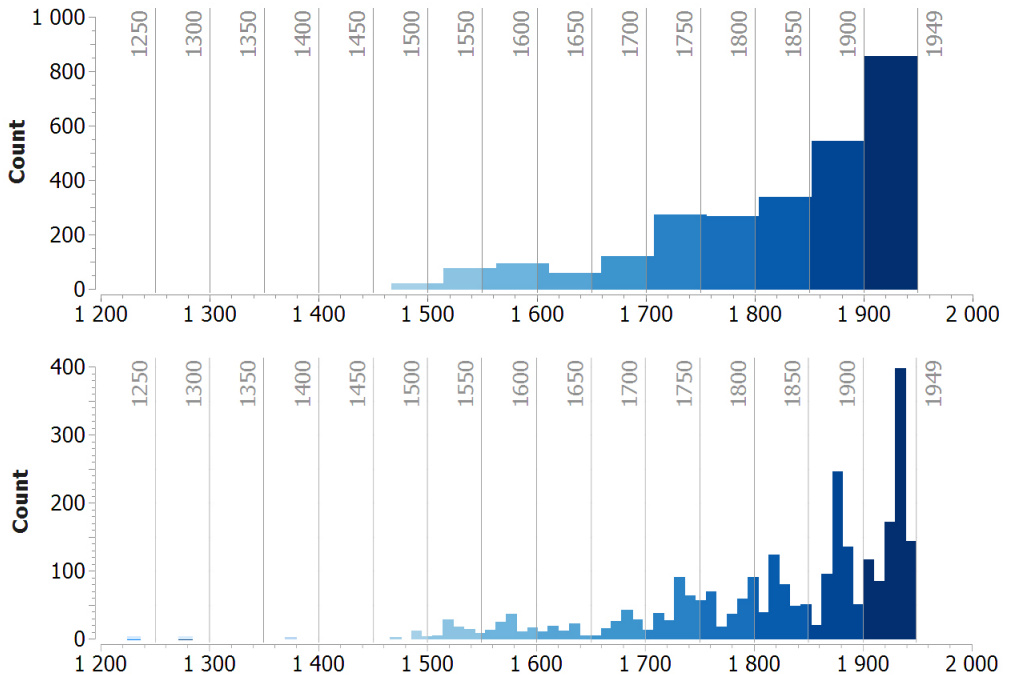
Chinese local gazetteers contain a latent lexicon of architecture distinct from the architectural experts' language in either ancient or modern times. As an example, this mapping shows the contrasting results of 'da-mu-zuo' 大木作 (lit. large scale wooden structure) and 'mu-liang' 木樑 木梁 (lit. wooden beam) in spatio-temporal dimensions after text-mining the *Difangzhi* source. The former is a basic technique term of Chinese architecture while it appears surprisingly scarce in the Chinese local gazetteers in spatio-temporal dimensions. The latter, instead, hit considerable results about wooden structure. The in-depth review of the hit contents in context reveals that 'mu-liang' not only denotes the apparent meaning of wooden beam (an ingredient of structure), but also connotes the horizontal timberwork system.



Map 1: The Source: Spatio-Temporal Distribution of the 3999 Volumes of Chinese Local Gazetteers (Difangzhi)



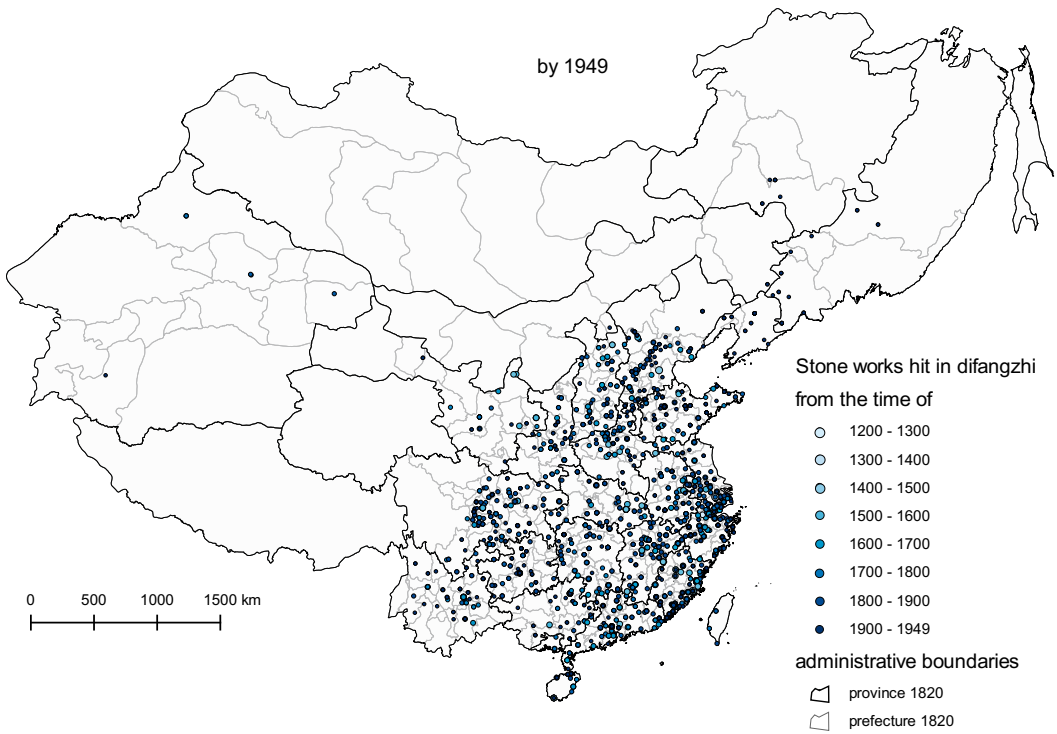
Map 2: Starting with Keywords Modelling: Contrasting results of 'da-mu-zuo' and 'mu-liang', showing the Chinese local gazetteer has its vocabulary of architecture distinct from the experts'.



Map 3a: Chang-Xue Shu (2018), *Reading the Raw Results with Histograms*.

Take the thematic topic of stonework for instance. After review and disambiguation, all the hit contents pertinent to stonework were added up; EXCEL and QGIS were used as tools. Then the assembled results were automatically calculated into quantitative histograms in the QGIS. The histograms could tell how frequently stonework activities were written up in the corpus of Chinese local gazetteers.

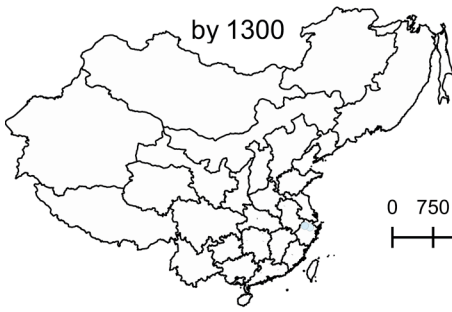
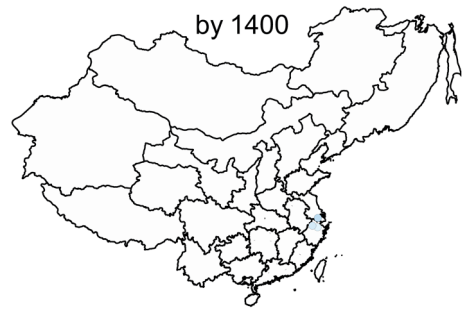
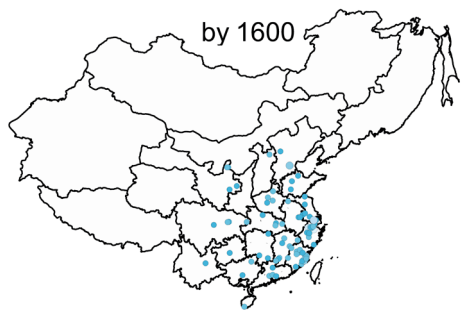
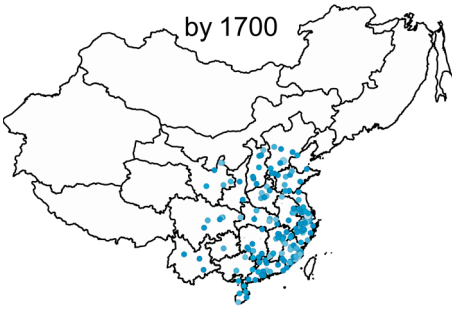
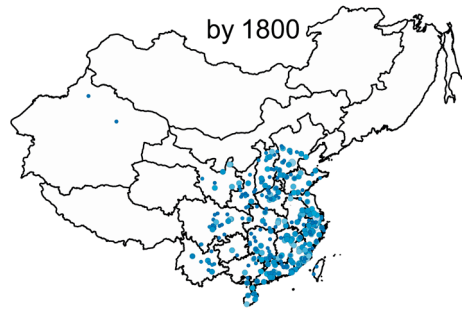
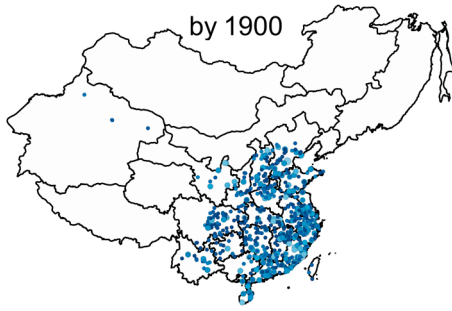
In this mapping, two histograms result from the same results counted at different points in time. The diagram at the top dealing with longer intervals (50 years) visualises the general trend that requires 'distant reading' (Moretti 2013), while the one at the bottom with shorter intervals (10 years) requires 'close reading' comparatively.



Map 3b: Chang-Xue Shu (2018), *Analysing and Synthesising the Hidden Historical Structures in space*.

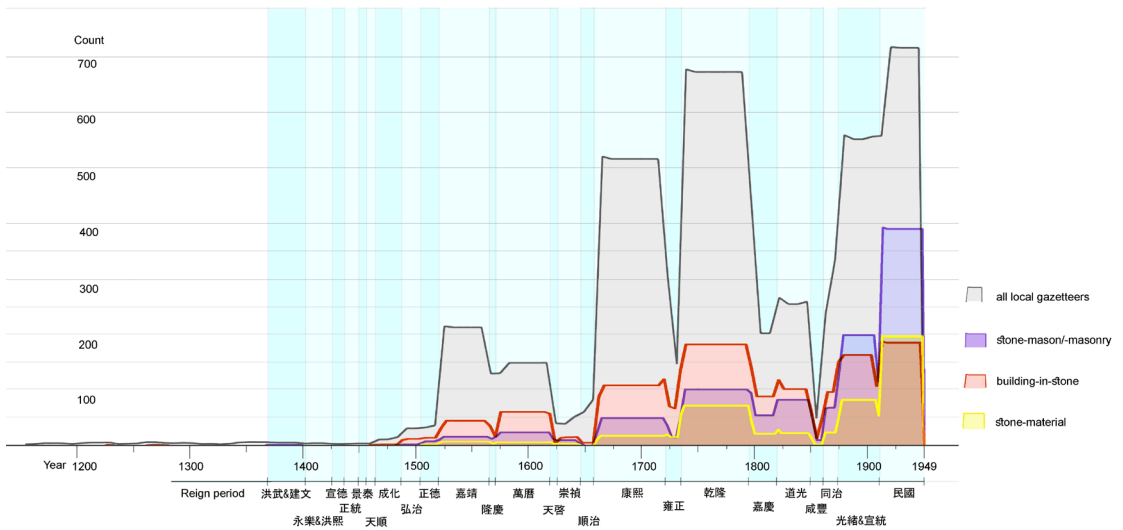
Following 3a, the assembled results of stonework were broken down at equal intervals (e.g. 50 or 25 years) and the changes were observed step by step in geography. The maps in 3b show the process in part (at intervals of 100 years). The changes are visualised in a cumulative manner.

The mapping reveals a changing historical structure of the intellectual knowledge of stonework in space. It proves that a spatial structure was well established from 1600 to 1700 at the latest. It also visualises how greatly the spatial structure was developed in the Qing dynasty (1644-1911) and in the Republic era (1912-49).



0 750 1500 km
|-----|

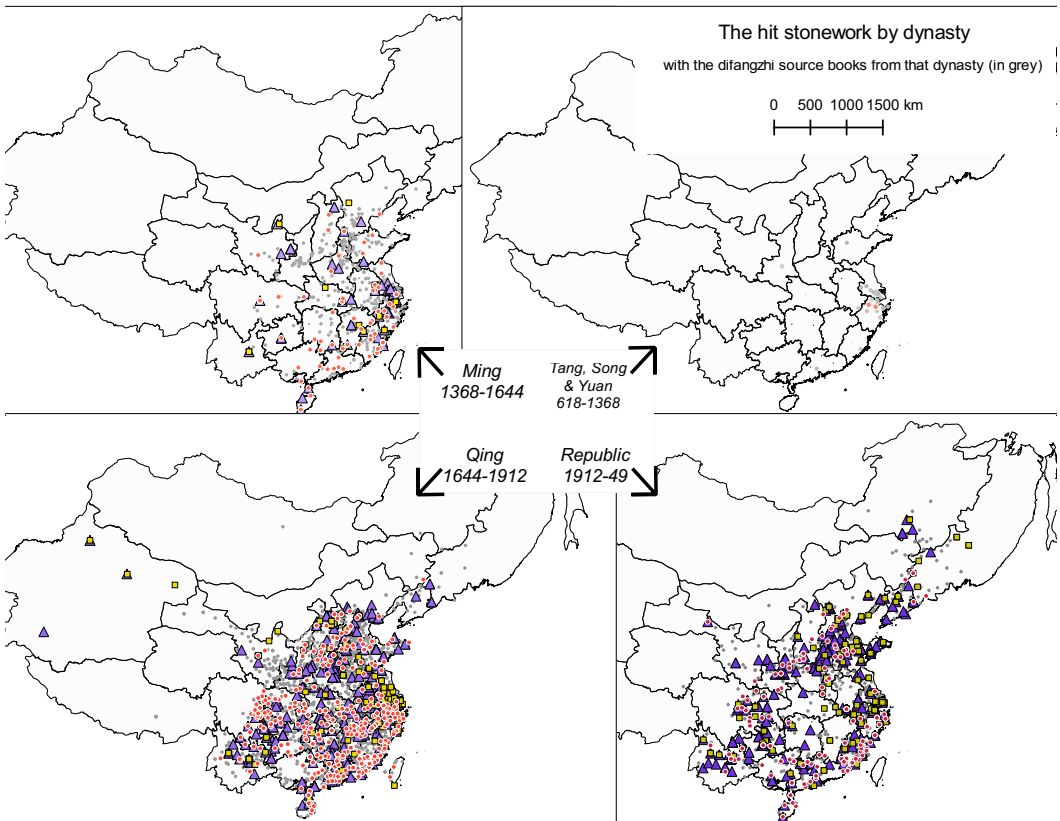
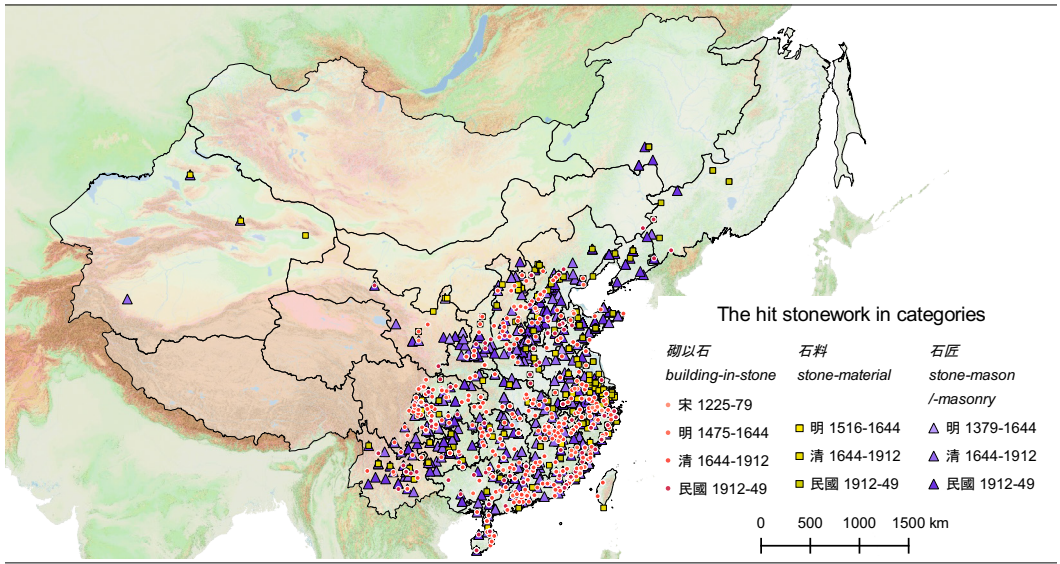
Hits of stonework in time and space.
Breaking down the results at equal intervals,
visualized accumulatively



Map 4a: Chang-Xue Shu (2018), *Quanti-Qualitative Analysis through Line-Chart Mapping*.

The hit results of stonework contain three principal categories: ‘building-in-stone’ (emphasising on the action or activity), ‘stone-material’ (materiality), ‘stone-mason/masonry’ (linked to the labour). Each of the categories generates a line chart representing the results of that category in quantity-time correlation, and the quantity was counted by page. The three line graphs, together with the quantity-time graph of the *Difangzhi* source (the dark grey line graph counted by volume), were layered along the same timeline. It was supplemented with another timeline graph marking Chinese reign periods (*chaodai* 朝代) of the Ming and Qing dynasties (rendered in two shades of light green alternatingly).

In this line-chart mapping, similar trends in rises and drops are apparent between the line graphs, with differences visible too. It shows that the absolute count of the hits in a particular period are framed by the volumes of the *Difangzhi* source in that period. Therefore, it is very necessary to introduce an index of ‘relative frequency’ to represent the intensity and density of a topic which was recorded by Chinese literati in *Difangzhi* in a defined period. Still, the mapping shows that ‘building-in-stone’ increased remarkably in the Qianlong period (1735-96, see the red line graph), and ‘stone-mason/masonry’ rose even more rapidly in the Republic period (1912-49, the purple line graph).



Map 4b: Geographical Distribution of Stonework in Thematic Categories and in Dynasties.

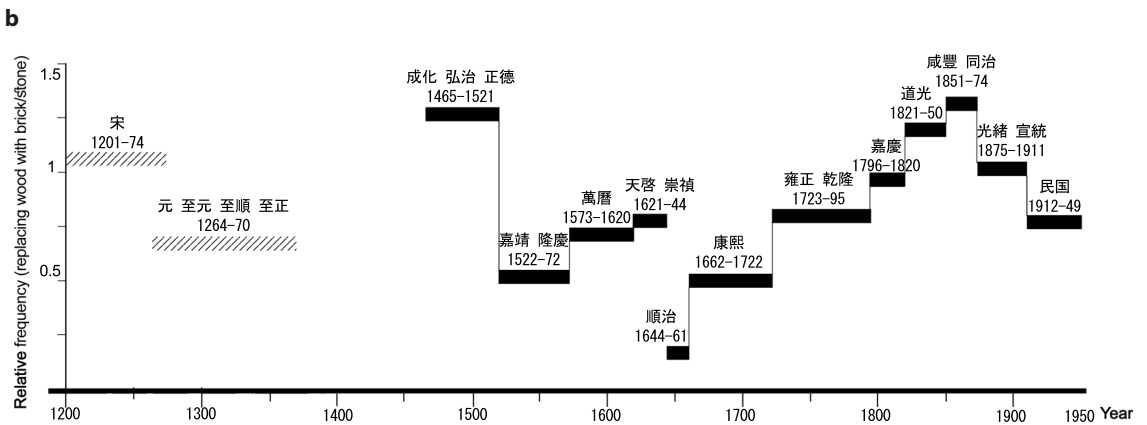
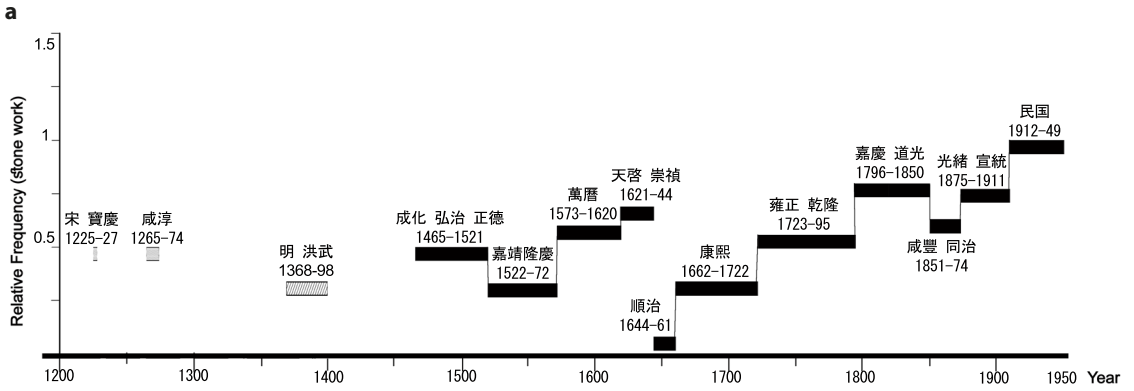
Map 4b: Chang-Xue Shu (2018), *Geographical Distribution of Stonework in Thematic Categories and in Dynasties*.

This mapping broke down the hit results of stonework by thematic category and dynasty respectively. The mapping at the top is a general presentation of the assembled results. It proves the wide geographical scale the Chinese practice and knowledge of stonework had reached by 1949. At the bottom, the mapping by dynasty shows several geographical structures of the knowledge. A geographical structure was formed in the Ming dynasty (1368-1644) at the latest. The structure developed and evolved differently in the Qing dynasty (1644-1911) and in the Republic period (1911-49), with distinct characters in either era. The most intensive development occurred during the Qing dynasty, and it appears continuous with the structure in the Ming (see the two maps at the left-bottom). In the Qing dynasty, moreover, the records of stonework extended over the regions in the northwest (via Hexi Corridor) and southwest (largely in Sichuan, Yunan and Guizhou). After the first half of the twentieth century, the development formed a σ -shape structure: few records are from regions of Central China yet remarkable traces are found over the northeast (see the map of Republic time in the right-bottom).

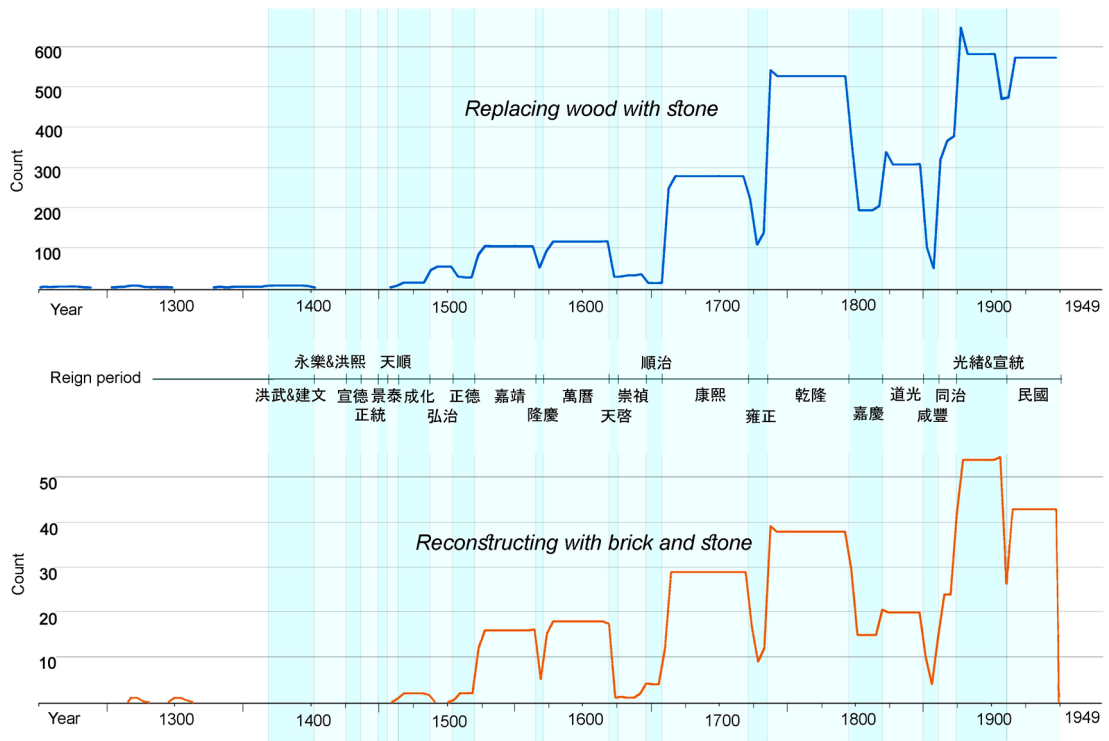
Maps 5a and 5b: Chang-Xue Shu (2018), *The Relative Frequency in Reign Periods*. The results of stonework (5a) and replacing wood with brick and/or stone (5b).

An index of 'relative frequency' was introduced and calculated, concerning the facts shown in 4a — quantitative limits of the source books unavoidably impact the hit results, and all the trends are closely linked to reign periods. The mapping of 'relative frequency' correlated four parameters: the counts of the source book (by volume), the counts of hit results (by page), metadata of 'book year', and reign periods. The index of relative frequencies in different reign periods was calculated. They were then transformed into a line-graph, where each horizontal line segment represents how intensive and dense the hit records are in that significant period.

The mapping of 5a dealt with the hit results of stonework, and 5b the hit results of 'replacing wood with brick and stone.' 5a and 5b are compatible in the following three aspects. (1) Both exhibit a sudden drop (or disruption) at the change from the Ming to the Qing dynasty, which may be explained as a consequence of the political replacement. (2) Both show stable increases in the periods of 1522-1644 and from 1644 to the end of the twentieth century respectively. (3) Both exhibit a high phase covering the three middle-Ming periods of 1465-1521 (成化, 弘治, 正德). However, 5b has very distinct trends: (4) The increase in 1465-1521 is exceptionally high compared to that shown in 5a; the reasons need explanation. (5) the relative frequency in 5b drops off after 1875, which is not exhibited in the case of stonework in 5a; this implies that new building material became available, or simply that the traditional activity of 'replacing wood with brick and stone' became less concerned by *Difangzhi* compilers.

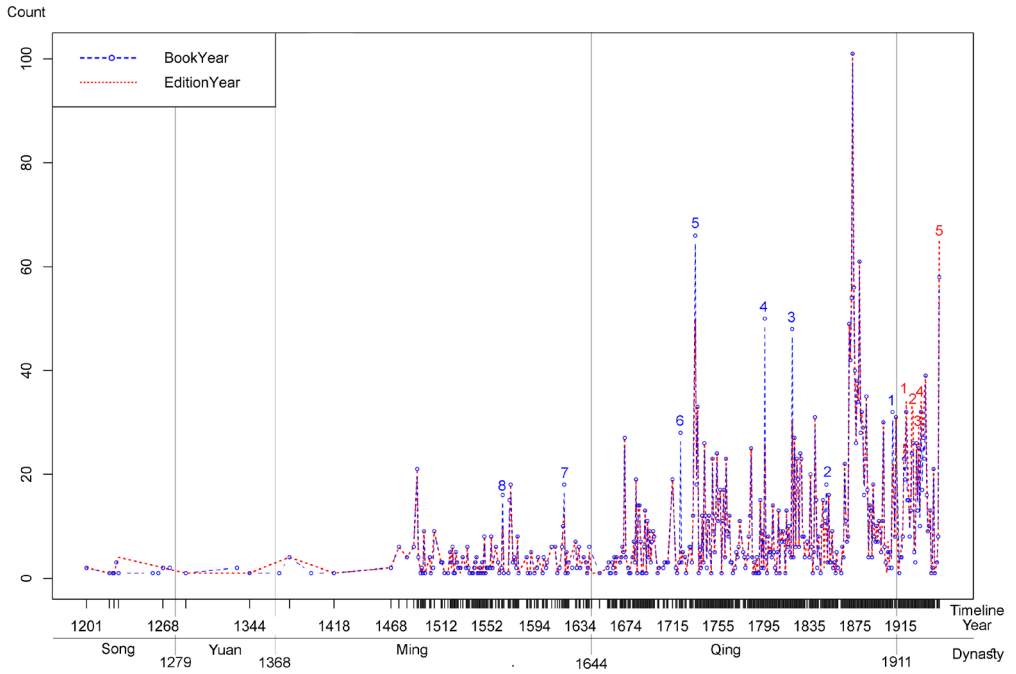
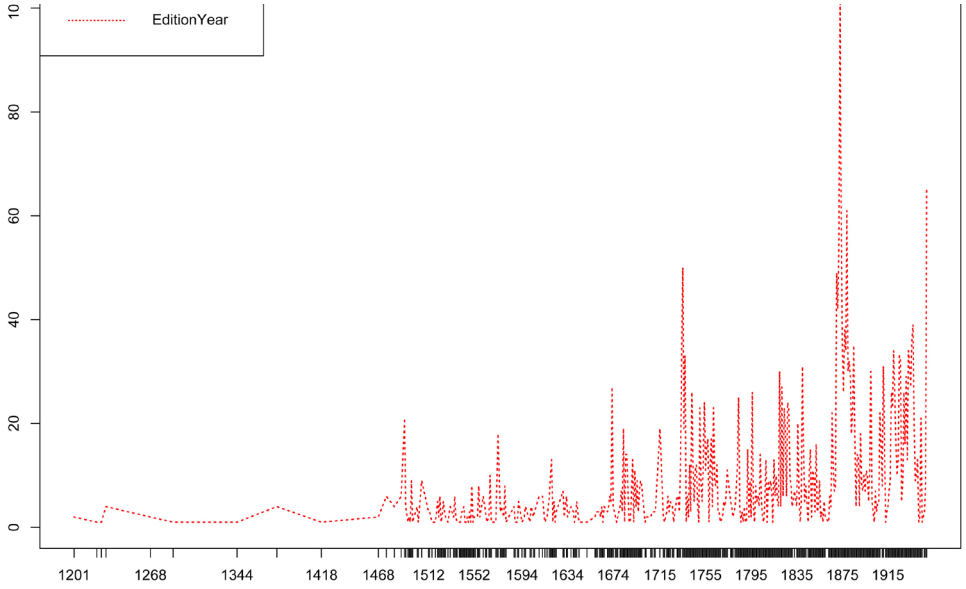


Maps 5: The Relative Frequency in Reign Periods. The results of stonework (5a) and replacing wood with brick and/or stone (5b).



Map 6a: Chang-Xue Shu (2018), *A Critical Result: Replacing and Reconstructing (Wood) with Brick and Stone*.

The following Maps 6, 7 and 8 provide the most critical evidence of the historical fact of using mineral building materials: 'replacing wood with brick and stone'. Earlier scholarship has not yet discussed the phenomenon of replacement from wood to masonry structure (stone or brick masonry) in Chinese architecture. Map 6a consists of two count-year diagrams, showing the thematic results of 'replacing wood with stone' and 'reconstructing with brick and stone' respectively. The trends in these two charts are quite similar and compatible.



Map 6b: Circulating the Knowledge via the Chinese Literati and the Local Gazetteer Books. A closer reading of the hit results of ‘replacing wood with stone’ in count-year diagram.

Map 6b: Chang-Xue Shu (2018), *Circulating the Knowledge via the Chinese Literati and the Local Gazetteer Books. A closer reading of the hit results of 'replacing wood with stone' in count-year diagram.*

The Chinese literati and the local gazetteer books constitute two kinds of agency promoting the circulation of architectural information. In the datasets collated through LoGaRT, one should understand the attribute 'book year' as the time the Chinese literati officially documented the practical knowledge or events of architecture and the attribute 'edition year' the time the practical information was (re-)circulated and disseminated. Map 6b shows these two modes of knowledge circulation. The two charts, 'count – book year' (blue) and 'count – edition year' (red), thus visualise two long-term structures of circulating the practical knowledge of architecture. The mapping of 6b used R — a software environment for statistical computing and graphics.

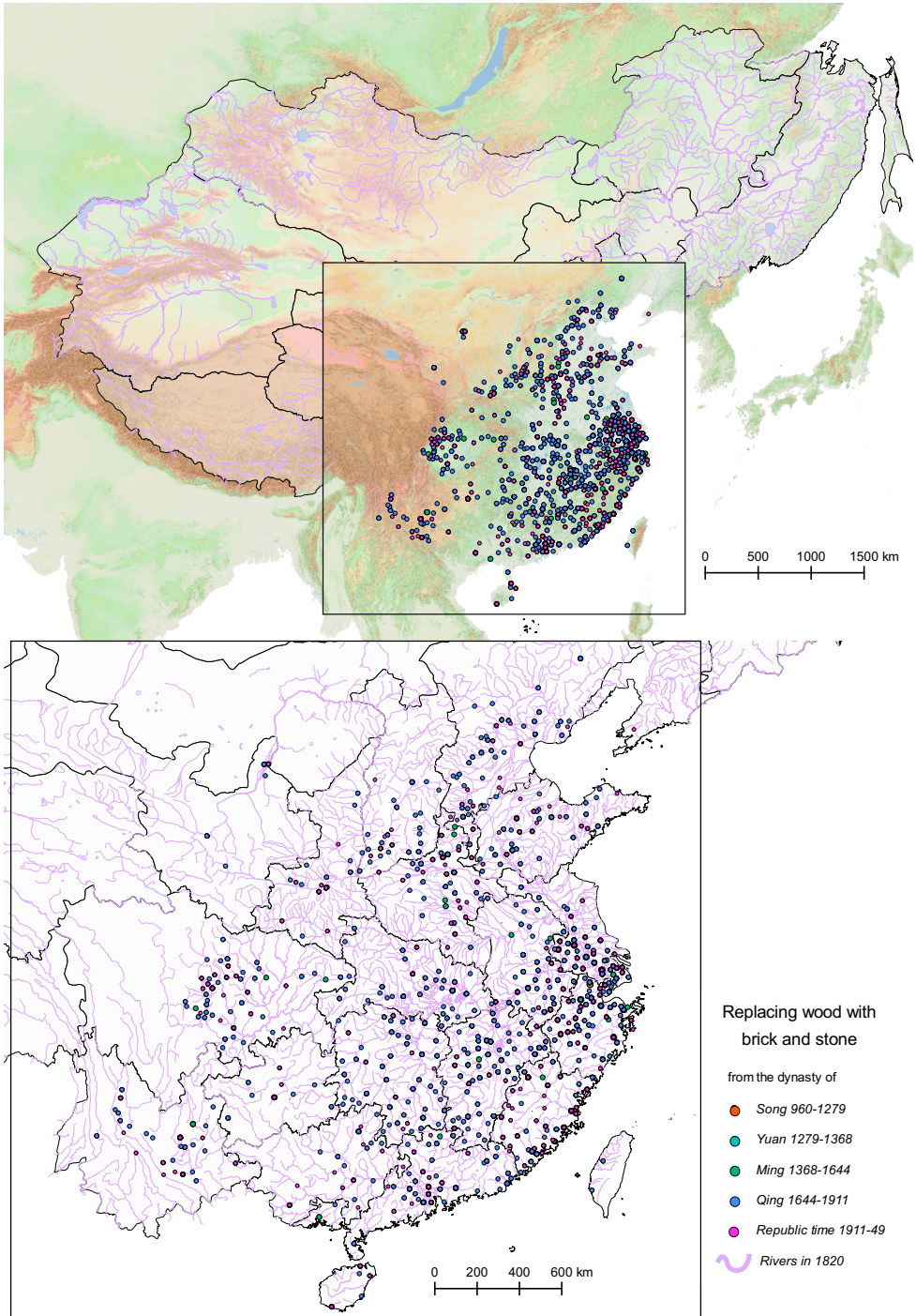
The blue and red charts were built on the same hit results of 'replacing wood with stone'. Overlapping the two line charts (6b-bottom), one can see their co-occurrence and difference. To make the difference more visible, I marked the significantly higher peaks in the blue line chart with bluish Arabic numerals and the higher peaks in the red line chart with reddish numerals. In comparison, it suffices to say that the practitioners' knowledge of 'replacing wood with stone' was remarkably absorbed by the Chinese literati in late-Ming and Qing eras (esp. 1566-1850), and the practical knowledge were increasingly (re-)circulated in the Republic era (1911-49).

The same method of R visualisation was applied to the dataset of the whole 3999 source books. The resulting visualisation confirms that the local gazetteers were largely compiled in Ming and Qing dynasties and even increasingly (re-)printed in the Republic era (1911-49), which is compatible with what 6b shows.

Please note that Map 6b resulted from the same EXCEL dataset that the 6a-top diagram rested on, but the 6a-top was processed by LoGaRT.

Map 7: Chang-Xue Shu (2018), *Replacing Wood with Brick and Stone.* Mapping all the pertinent results from 1201 to 1949 in terrain (top) and contextualising them in the 1820 river system (bottom).

This mapping shows that most of the records of replacing wood with brick and stone were apparently located along rivers. The mapping corresponds with the fact that the contents are largely recorded in the local gazetteers in the context of building city walls, fortification, roads, schools, temples, bridges and other hydraulic works like ferry ports, culverts, banks, dykes and dams; they were arranged under the thematic section names of 'construction', 'ferry and bridge', 'irrigation', 'embankment and weir', 'city and fortification', 'school', 'landscape and geography', and 'metal-stone'.

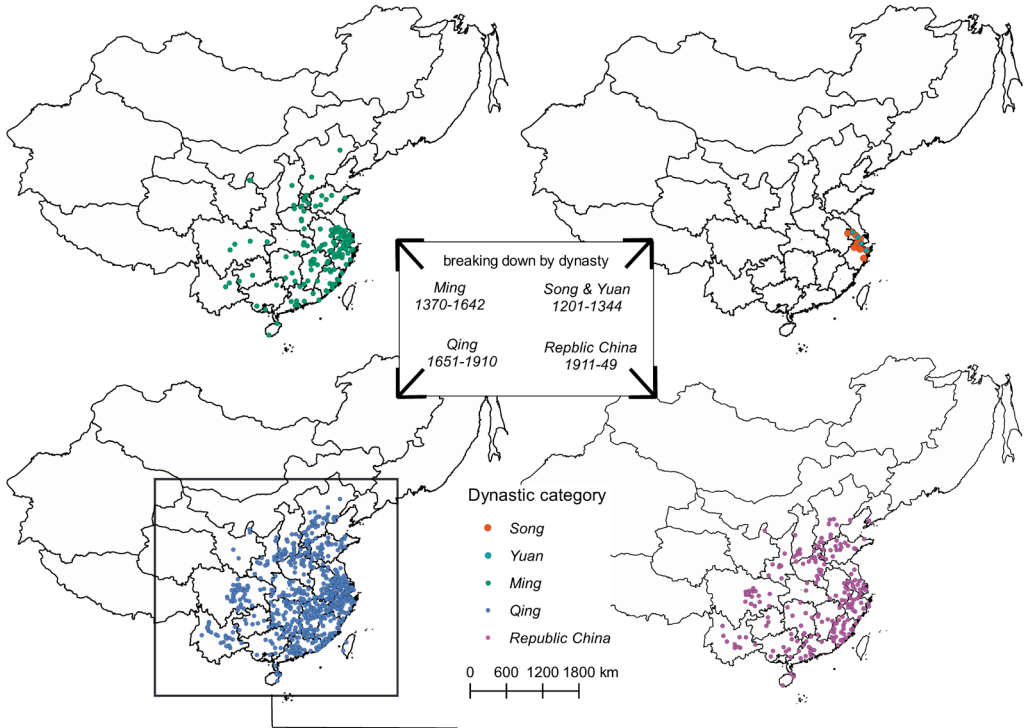


Map 7: Replacing Wood with Brick and Stone. Mapping all the pertinent results from 1201 to 1949 in terrain (top) and contextualising them in the 1820 river system (bottom).

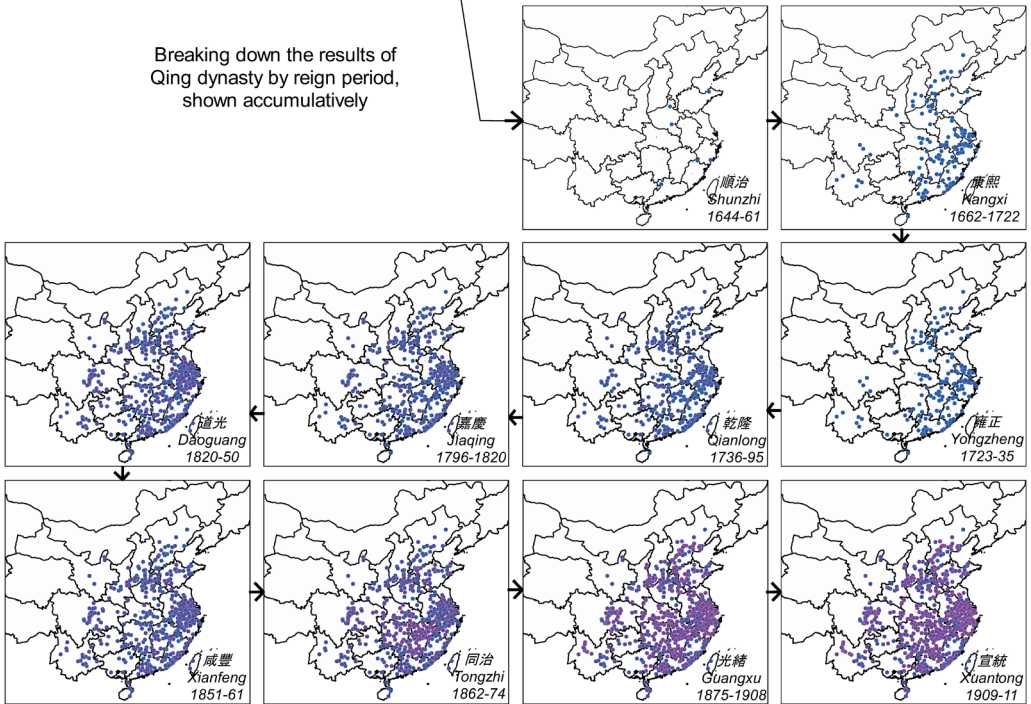
Map 8: Chang-Xue Shu (2018), *Replacing Wood with Brick and Stone*. Analytical GIS mapping, by breaking down the results in dynasties, non-cumulatively (top) and breaking down the results of the Qing dynasty by reign period, cumulatively (bottom).

The most and most frequent occurrences of the activity appear in the Qing dynasty, and it is in the Qing dynasty too that the widest and most intensive spatial distribution appears [see Map 5b, Map 6, Map 8-top]. This analytical mapping in Map 8-bottom proves that by the end of the Kangxi period (1662-1722) at the latest the spatial structure of this replacing-wood-with-brick-and-stone activity had formed.

Results of replacing wood with brick and stone



Breaking down the results of Qing dynasty by reign period, shown accumulatively



Map 8: Replacing Wood with Brick and Stone.

