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Analysis of Correlation Features in Material Application for Architectural Design Based on Big Data Text Mining

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Abstract: This study conducted a big data mining and lexical co-occurrence network analysis on design texts sourced from architectural media over the past decade, systematically evaluating the application trends of materials in architectural design. This approach distinguishes itself from traditional case studies that rely on small samples of material applications in architectural design, thereby significantly enhancing the generalizability of the conclusions. The research reveals a 27.2% increase in the material–project frequency of architectural materials over the past ten years, indicating that the materiality of architecture is gradually making a comeback to counteract the trend toward architectural visualization. Within this context, material properties, material interactions, and material presentation in architectural components emerge as universal concerns in architectural design. Notably, the sustainability and energy efficiency of wood and concrete have emerged as pivotal topics in architectural practice, in addition to their structural functions. Additionally, over the past decade, the material–project frequencies of brick and stone have grown rapidly, with respective increases of 24.3% and 11.8%. Brick and stone primarily respond to the locality and style of architectural design by emphasizing their inherent texture and color, thereby enhancing the spatial perception and experience within the designs. This study lays the groundwork for quantitative research on the influence of building materials on architectural design, and it illuminates current trends and preferences in material application within architectural design, thereby empowering architects to make more informed decisions in their material selection.

Keywords: architectural design texts; building materials; big data text mining; lexical co-occurrence network; material–design characteristics

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1. Introduction

The interaction between architectural design and materials has long been discussed. The influence of materials on architectural design is evident, whether in the transition of the Doric Order from wood to stone or in the descriptions of "On Architecture" [1]. By the time of the neo-renaissance, Semper developed "Bekleidungs theorie" based on the characteristics of materials [2], and Loos inherited and further developed the theory, reversing the primary and secondary roles of structure and surface in the presentation of materials [3]. During the subsequent Bauhaus movement, material thinking continued to be integrated into architectural design [4], with the extensive use of concrete, steel, and glass in modern architecture creating a new architectural space [5]. However, after the 1950s, the globalization of architectural production and practice [6], dominated by landscape, virtualization, and exchange, led contemporary architectural design to become increasingly visualization-oriented [7]. With the development of artificial intelligence and virtual reality, this trend is only set to intensify—meaning that architecture attempts to ignore materiality, becoming a direct, immediate, and simple extension of drawings [8].

This reverses the relationship between the authenticity of architecture and the images, simplifying the complex materiality that traditional architectural design needs to consider into the mere derivation of architectural form [9]. In this process, issues surrounding building materials, including the locality of architecture, spatial experience (texture and color), and environmental impact, have all been marginalized in architectural design [10]. In the 21st century, the challenge of environmental degradation and diminishing resources have catapulted the sustainability of building materials to the forefront of architectural design [11]. The resurgence of regionalism has led contemporary architecture to develop a new vocabulary based on local materials [12]. This signifies that in the context of contemporary architectural design, the renaissance in the application of building materials has become one of the key strategies to address the loss of materiality and sense of place caused by the trend towards visualization.

However, given the complexity of architectural design, how to respond to the various uncertainties faced by contemporary architecture through different material strategies remains an important issue that needs further exploration [13]. Presently, most architectural design research focuses on representative architectural projects or case studies, and this is also true for research related to material applications in architecture [14–16]. Traditional architectural research often centers on how the use of building materials reflects the personal style of designers, such as Louis Kahn's use of hollow stones and exposed concrete [17], Álvaro Siza's use of white marble [17], and Peter Zumthor's expression of material textures [18]. In emerging research of architectural design, material-related case studies focus more on how materials address issues like sustainable development and green building [19]. For example, Carol and Alessandra analyzed the application principles of membrane material through case studies to guide sustainable architectural design [20], while Urszula synthesized cases from Germany, the Netherlands, Poland, and Denmark to analyze strategies for reusing recycled materials in architectural design [21].

This type of analysis raises two major issues, despite its ability to articulate some architectural design trends. First, compared to the vast majority of architectural works, representative architectural works are relatively scarce and are more likely to represent trends in architecture rather than actual realities [22]. The overwhelming majority of architectural projects, whether in terms of concept or technology, deviate in some way from these exemplary cases. Second, while the representative works may enjoy ample resources and ideal conditions, this is exceptional. In contrast, the majority of architectural works are constrained by factors such as budget, construction timelines, and on-site manufacturing challenges [23].

Therefore, finding a way to adequately represent the majority of architectural designs is the prerequisite of the present study on materials used in contemporary architectural design. Benefiting from the advancement of the times, we can obtain a large amount of information related to architectural design from architectural media on social media networks, such as ArchDaily [24] and gooood [25]. The open display mechanism allows architects to freely upload and display their design schemes [26], which not only provides architects from various regions a platform to showcase their architectural designs but also makes a significant contribution to architectural education [27]. The description of the scheme can directly reflect the architect's design concept since the design text and architectural pictures in each scheme are provided by the architects [28]. Such a study is more likely to use architectural design texts than architectural drawings to examine how materials are applied in architectural design [29]. Doing so can avoid two problems. First, it can avoid the problem of misidentification when using pictures to identify materials or architectural components, and no identification error exists in the architectural design texts. Second, even though various architects have varying viewpoints on architectural concepts, descriptions of material application in architectural design texts should be objective and fair [30].

This research aimed to develop appropriate methods to systematically evaluate the potential of material application in architectural design and analyze the trends and focal points of diverse material applications in contemporary architectural design. The architectural design texts from architectural media over the past decade were taken as the research objects, employing the Material–Project Frequency (MPF) approach to identify the types and application trends of representative building materials. Furthermore, through big data text mining, lexical co-occurrence networks are utilized to analyze the primary concerns, commonalities, and differentiating characteristics of various representative building materials in architectural design. Case studies are also conducted to validate the results of this research. The ultimate objective of this study is to reveal the current trends and preferences in material application within architectural design, thereby assisting architectural practitioners in making more rational material selections and optimizing their design decisions.

2. Materials and Methods

2.1. Materials

2.1.1. Data Collection

We gathered a variety of projects about architectural design text on the architectural media from 2010 to 2020, with a total of 35,656 report files serving as the basic data of this study (access date: 20 October 2022). The selection of the data range spanning from 2010 to 2020 is dictated by the annual project volumes recorded in the architectural media. Before 2010, the architectural media featured a relatively limited number of projects. For instance, in 2009, there were 1500 projects approximately reported, marking a quarter reduction in data volume compared to 2010, which boasted over 2000 projects. Furthermore, taking into account the construction cycle of projects, which typically spans 2–3 years in our investigation, we have designated 2020 as the terminal point for project analysis. This decision aims to mitigate the potential disruption caused by incomplete projects and ensure the relative stability of the data set we have collected. The following information was collected: year, name, country, type, area, and design text of the project. These data were all obtained by Web Scraper, which can directly build crawling tool scripts in web pages and collect and export web data for further text analysis [31]. The programming structure used by Web Scraper to collect information comprises three layers (as shown in Figure 1): the first layer is the root file used to record the set of items to crawl; the second layer is the project link, which is used to index the HTML code of each item in the project set; and the third layer is the relevant information of each project. After crawling, the data can be exported to CSV format. The original information collected was in English. In addition to this, we selected two representative architectural cases for analysis to validate the accuracy of text co-occurrence analysis.

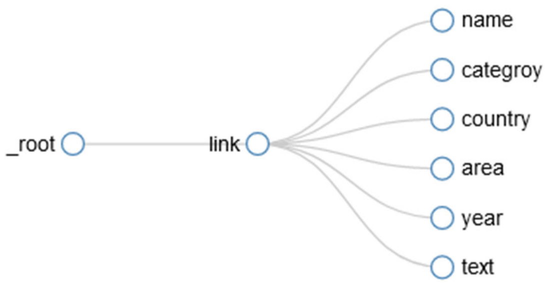

Figure 1. Information capture script structure.

2.1.2. Data Statistics Overview

The registration information of different projects on the architectural media exhibits some differences. The code should be correctly modified so that the Web Scraper grab efficiency is maintained above 95% of the entire sample, considering the project's representativeness in the overall sample. The total number and efficiency of projects in each year are listed in Table 1.

Table 1. Statistics of the scraped architectural design texts.

Year	Scraped Sample Size	Total Sample Size	Efficiency
2010	2008	2016	99.60%
2011	2167	2179	99.40%
2012	2464	2510	98.17%
2013	3012	3168	95.08%
2014	2929	2990	97.96%
2015	3452	3559	96.99%
2016	3610	3784	95.40%
2017	3939	4055	97.14%
2018	4275	4405	97.05%
2019	4327	4385	98.81%
2020	3481	3558	97.84%

Table 1 reveals that over the past 10 years, the total number of actual projects gathered from the architectural media increased and peaked in 2018. On the one hand, this proves how the scale of architecture has expanded significantly in recent years. On the other hand, the influence of the architectural media in the field of architectural design has been increasing. According to the construction production cycle, it takes two or three years from the completion of the design scheme until the completed product is ready. This explains why the total number of construction projects in this survey peaked in 2018.

The following building materials were screened and analyzed in this study based on research on widely used building materials in architectural design and the market: concrete (cement, mortar), wood (wooden, timber), glass, brick, tile, ceramic, stone (slate, granite, marble, sandstone, gypsum), metal (steel, aluminum, iron, copper), bamboo, plastic, and coating (paint).

2.2. Methods

2.2.1. Research Process and Screening Method

The research process of this study is shown in Figure 2.

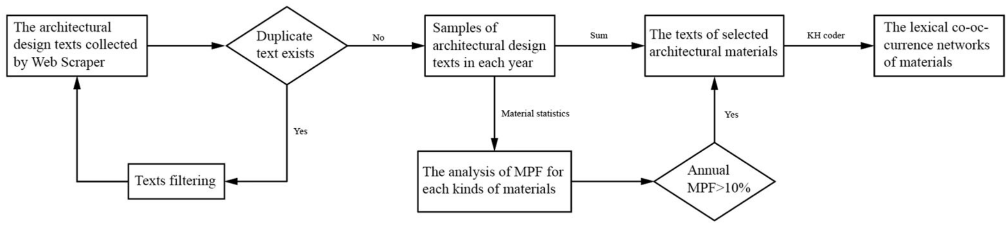

Figure 2. Flow chart of research process.

The research process of this study is shown in Figure 2. The gathered architectural project design texts were first carefully screened to obtain the corresponding architectural design texts for each year. Second, the material-related texts of architectural projects in each year were extracted and summarized to calculate the MPF. Third, based on the values of the MPF screening, building materials that fulfilled the requirements were selected, and the corresponding word frequency and relevant context were then sorted. Finally, the co-occurrence of keywords and the meaning of word group types were analyzed according to the completed architectural design texts.

The degree of interest and use of materials in architectural design differ due to the significant difference in the overall amount of architectural design projects completed each year and project types. Therefore, it is not of great significance to only compare the changes in the number of material texts in each year. Given that the focus of this study is the application of building materials in various architectural designs, *MPF* was selected as the measurement of the importance of various building materials in architectural designs. Its calculation formula is as follows:

$$MPF = \frac{M_f}{P_{sum}} \tag{1}$$

where MPF represents the material–item frequency of the corresponding material; M_f represents the frequency of material occurrence in the statistical text of the year, which can be determined using the "Word Frequency list" function's statistics in KH Coder; and P_{sum} represents the total number of projects in the year, which is calculated from the total number of actual projects grabbed by Web Scraper.

2.2.2. Text Mining and Vocabulary Co-Occurrence Network

This study used KH Coder for text mining and vocabulary co-occurrence network construction [32]. Stanford POS Tagger 4.2.0 is used for word extraction in KH Coder to distinguish between the first letter and the case of words. The software avoids singular and plural forms of words. The R Project and MySQL were used for statistics and data management, respectively [33]. KH Coder has been developed for quantitative text analysis in various academic fields, such as sociology and culturology, and is usually used to evaluate indicators that are difficult to quantify, such as feelings and culture [34–36]. The study of the impact of materials on architectural design through design text provided by architects is entirely consistent with this. Therefore, KH Coder was selected for text mining in this study, and the focus of material application in architectural design was examined using clustering and a Jaccard index-based lexical co-occurrence network [32]. Among them, the Jaccard index can be used to describe the degree of coincidence between text units containing any two words, which is suitable for evaluating the similarity between finite sample sets [37,38]. The calculation formula is as follows:

$$J(A,B) = \frac{|A \cap B|}{|A \cup B|} \tag{2}$$

where $J(A,B)$ denotes the Jaccard index of word A and word B, respectively. A is the set of words A contained in the general architectural design text, and B is the set of words B contained in the general architectural design text; the Jaccard index range is between 0 and 1. The word co-occurrence network diagram was created in descending order based on the Jaccard index of the co-occurrence relationship between all the words in the text. The lexical contribution network with the minimum spanning tree was constructed in this study based on an evaluation of the initial 150 co-occurrence relationships (edges) of each material co-occurrence network. This was determined from the sample size of the architectural design text and the integrity of the vocabulary co-occurrence network. This not only reduces unnecessary information but also increases the readability of the co-occurrence network. The words represented by each network node are located in the node's top right corner, and each word community is automatically generated by KH Coder and marked with numbers in the subgraph.

3. Results and Discussion

3.1. Systematic Sorting of Material Occurrence Frequency

Based on whether the material vocabulary was included, Web Scraper retrieved and summarized the annual project design texts. After deleting duplicate values, the MPF was used to statistically analyze all the design texts related to the material. According to the MPF of materials, the aforementioned 25 types of materials can be divided into three categories: those with an MPF greater than 10% (Figure 3), those between 5% and 10% (Figure 4), and those smaller than 5% (Figure 5). Figure 1 shows that the MPF of the word "material" has been tortuously increasing over the last 10 years. This indicates a continuous rise in attention to "materials" in architectural design in recent years. Architectural design is gradually moving away from the trap of visual presentation and returning to a focus on the materiality of buildings.

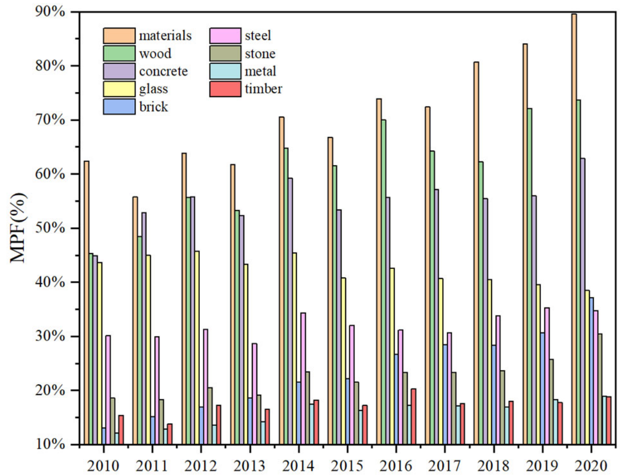

Figure 3. Summary of annual changes of materials with MPFs above 10%.

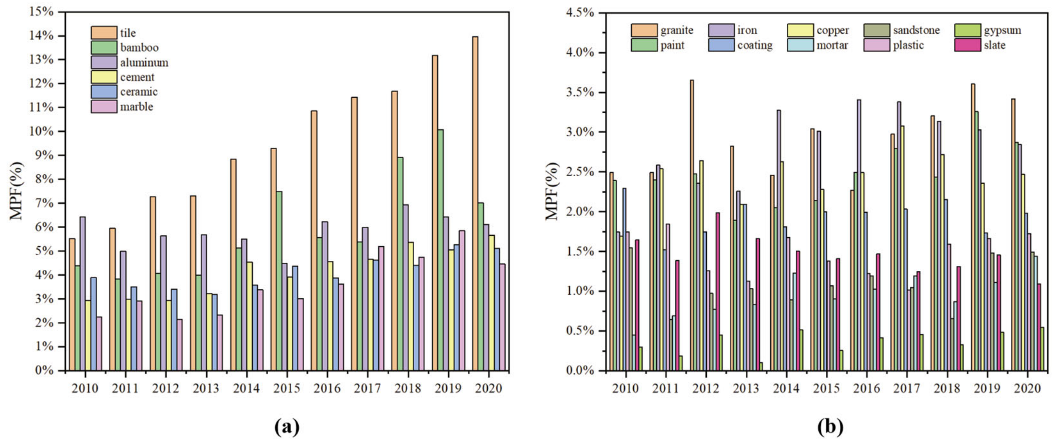

Figure 4. (**a**) Summary of annual variation of some materials with MPF between 5–10%; (**b**) Summary of annual variation of some materials with MPF below 5%.

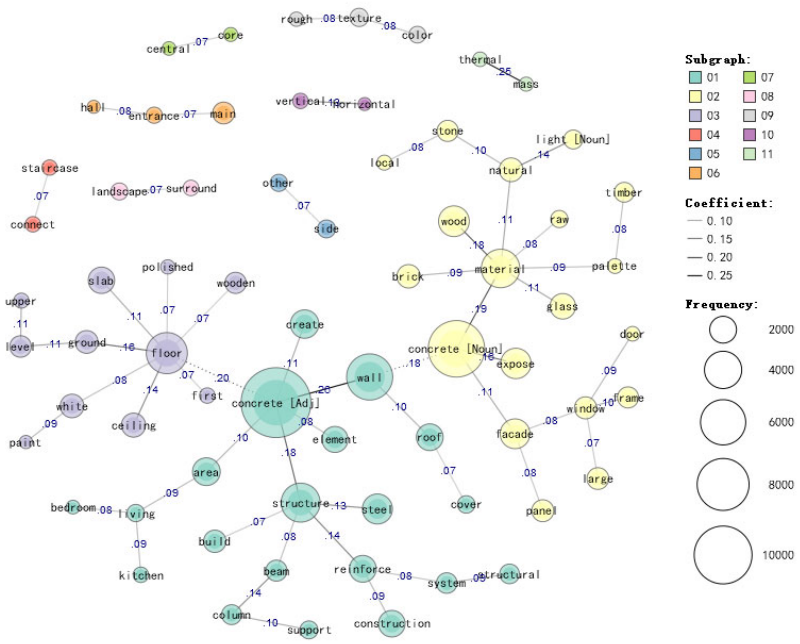

Figure 5. Lexical text co-occurrence network based on "concrete".

Figure 3 shows eight types of materials. These materials are regarded as common building materials because of their high frequencies of utilization in architectural design. The MPFs were divided into two categories. The first comprised "wood", "concrete", "brick", and "stone", whose MPFs increased significantly (more than 10%) from 2010 to 2020. The MPF curves of "wood" and "concrete" were similar to those of "material", which meant that their application occupies the main position in all kinds of materials. However, compared with the growth rate of concrete's MPF, the growth rate of wood's MPF emerges as higher, surpassing that of concrete for the first time in 2013 and maintaining a leading position ever since. This indicates that the use of materials produced with low environmental impact is developing in architectural design, which is directly correlated with the burgeoning green building design in recent years. The increase in the MPFs of "brick" and "stone" has deeper implications. It suggests that architectural design is gradually moving away from the universal modern architectural approach [39], with local materials becoming a new focal point in the diversification of architectural design. This trend is particularly evident in the increased MPF of "brick". In addition, from 2010 to 2020, the MPF curves of "glass", "steel", "metal", and "timber" fluctuated. "Glass" and "steel" remain the mainstream materials in contemporary architectural design, while the frequency of "metal" and "timber" is slightly lower, being involved in less than 20% of architectural cases.

The remaining 16 materials have a frequency of less than 10% in architectural design, with six materials having an MPF between 5% and 10% (Figure 4a). The remaining sixteen materials have a frequency of less than 10% in architectural design, with six materials having an MPF between 5% and 10% (Figure 4a). This may be due to the structural properties of these materials. For instance, "tile", like "brick", has a strong regional character but is not as widely used as brick, and it is difficult to reflect how the materials affect architectural design. The MPF values of the final 10 types of materials are less than 5%, and the MPF curve varies significantly across years (Figure 4b). This shows that the uses of these materials were determined by the construction projects themselves, and it is difficult to determine the consistency of their use.

3.2. Overview of Material Lexical Co-Occurrence Network

Although MPF can be used to evaluate the attention paid to various architectural design materials, it cannot analyze the key factors (texture, structure, orientation, etc.) influenced by the building materials. These issues can be clarified through the connection between words. Therefore, the material must serve as the core of a lexical co-occurrence network when discussing the connection between different words or word groups. Considering the frequency of material application and the sample size, using a 10% MPF to measure the general applicability of the collected texts about material usage is appropriate. Therefore, this study conducts a separate co-occurrence network analysis of vocabulary for building materials with an MPF greater than 10%. The results are shown below.

The number of text units indicates the total samples containing material entries, and their ranking aligns with the MPF ranking (Table 2). Co-occurrence vocab means the total number of words contained in the co-occurrence network, indicating the scope of the co-occurrence network. Main topic groups refer to interconnected word groups in a co-occurrence network, while scattered word groups refer to independent word groups that are unrelated to other topics. The main word group prop. represents the proportion of words in the co-occurrence vocab within the main topic groups, indicating whether the structure of the co-occurrence network is loose. From the number of words in the co-occurrence network of each material text, wood materials have the broadest focus, including 79 words for "wood" and 81 words for "timber". This demonstrates the flexibility and versatility of wood in the presentation of building materials [40]. In contrast, concrete, glass, and steel, which are most closely related to modern architectural design [5], have the fewest words in their co-occurrence networks, consistent with material application strategies in modern architectural design. Allowing multiple material uses simultaneously in modern architecture is challenging, as it will result in a blurring of the boundaries between form and function [41]. Additionally, analyzing the relationship between the main word clusters and scattered word clusters in the material co-occurrence network reveals that the total number of word clusters for most materials is 11. This implies common focal points in the application of materials in architectural design, summarized by Lisa and Ine as context, manufacturing, material aspects, and experience [29]. In this study, these key points are summarized into three aspects: material properties, interactions between materials, and the presentation of architectural components. In terms of cluster association, the emphasis on wood, concrete, metal, and stone shows weaker correlations, as reflected in the proportion of main word clusters of these materials in the entire co-occurrence network (less than 80%). This is related to the suitability of the advantageous properties of materials, meaning these materials are primarily used to fulfill specific functions. For instance, the structural properties of concrete and wood are linked to load-bearing structures, while the malleability of metal is associated with cladding. Conversely, materials with tighter cluster associations have broader applications.

Table 2. Analysis of vocabulary co-occurrence network for relevant building materials texts related to MPFs above 10%.

Materials	Text Units (Number)	Co-Occurrence Vocab (Number)	Main Topic Groups (Number)	Scattered Word Groups (Number)	Main Word Group Prop
Wood	22,259	79	3	11	68.3%
Concrete	19,715	68	3	8	73.5%
Glass	14,862	65	6	5	83.1%
Steel	11,480	71	7	4	88.7%
Brick	8820	72	7	4	88.9%
Stone	8250	76	4	7	78.9%
Timber	6258	81	6	5	84.0%
Metal	5809	75	3	8	78.7%

3.3. Concrete, Glass, and Steel

Concrete, steel, and glass form the material foundation widely used in modern architectural design [5]. Their characteristics, unaffected by local material constraints, have led to an industrial assembly line production in architecture [23], significantly increasing the scale and speed of modern construction compared to previous eras. However, with the impact of emerging issues such as composite building structures [42] and sustainable development [30], the focus on these materials in architectural design needs to be re-examined to understand the influence of these new architectural design issues on the materials used in modern architecture.

The co-occurrence network analysis of texts related to "concrete" shows that the primary focus of concrete material application is on its properties, interactions with other materials, and its presentation in horizontal building components. In architectural design, the focus on concrete properties is further divided into two branches (Subgraph 01). First, the branch with "structure" as the core word indicated that the concrete had garnered interest as a structural material [5]. The structural system was composed of "wall", "beam", "column", and "roof". It also exhibited the universality of the application of reinforced concrete in architectural design. Second, the "area" branch connected with "concrete" represented the functional requirements that attracted attention for architectural design. Compared to the latter, the branch network constructed by the former is more closely related to "concrete", with coefficients generally exceeding 0.10. This indicates that in the utilization of concrete within architectural design, there is a greater emphasis placed on structural properties than on spatial functionality, which is consistent with the conclusions of previous research [42]. The interaction between concrete and other materials is another focus of architectural design (Subgraph 02), which also has two branches. First, with "material" as the core word, one branch focused on the interaction of concrete with different materials, such as "wood", "brick", and "glass". Some material properties, derived from the interaction topic, have also been of interest in architectural design, such as the raw material of concrete and natural light. Second, the connection of the "facade" with concrete implied that concrete played a role in the building's conceptual expression and visual presentation to the exterior, as the interface introduces a building's essence [43]. Different from the façade, the horizontal elements like "floor" and "ceiling", concrete is often used in a concealed manner, as indicated by terms like "polished" and "paint", with concrete typically serving as a base layer for material finishes. The connection between the three main word groups of concrete implies that a certain synergistic effect exists among the structure, functional requirements, interaction of materials, and facade. In addition, there are also some elements that respond to contemporary architectural design. Subgraph 09 composed of "rough", "texture", and "color" signifies a trend in contemporary design towards enriching the visual effects of concrete, endowing architectural exteriors with greater expressive power [44]. Subgraph 11 addresses the issues of energy efficiency and sustainable development in architectural design by developing the insulation properties of concrete [45], which differs from previous research [46]. Notably, judging from the frequency of the "thermal" and "mass", over 10% of the textual units have featured this concept as a key element, which can be attributed to the rise of green building design [47]. Concurrently, the vocabulary co-occurrence network provides a perspective that differentiates stairs from their traditional structural aspects, suggesting that in architectural design, the connection function of stairs is prioritized over their structural attributes.

The co-occurrence network of texts related to "glass" covers more core issues than that of concrete (Figure 6), in addition to material properties (Subgraph 02), material interactions (Subgraph 04), and material presentation in horizontal building components (Subgraph 05). Glass has a direct impact on spatial functionality and the improvement of the building's light environment, continuing the modern architectural focus on glass transparency in recent designs [48]. "Area" serves as the core word in Subgraph 01, representing the functional requirements of the spatial layout in a floor plan [49]. The components of architecture are usually composed of opaque materials, such as concrete or wood, but the embedding of glass can modify the properties of these opaque components, connecting the entire building space in place of obstruction, thus changing the organizational form of space in architectural design. In this topic, glass contains more elements than wood or concrete. This suggests that the visual connectivity provided by glass offers more possibilities for spatial functionality in architectural design, typically achieved through the "door" branch connected to this word cluster (Subgraph 06). Structural parts related to the transparency of glass are also reflected in Subgraph 02. However, as an opening element in architectural design, the structural aspects of glass are usually realized by other materials and are not the primary focus of architectural design. Similarly, the word cluster centered on "light" represents the role of glass in enhancing the light environment of buildings (Subgraph 03). The transparency of glass also serves as the underlying logic that interconnects architectural elements. Verbs like "bring" and "allow", which are connected to "light", may reflect perceptual changes caused by glass, which enhances the spatial experience. The phenomenological transformation stemming from the material properties of glass is also manifested in the lexical sets of "visual connection" and "public–private", highlighting the significant role of glass transparency.

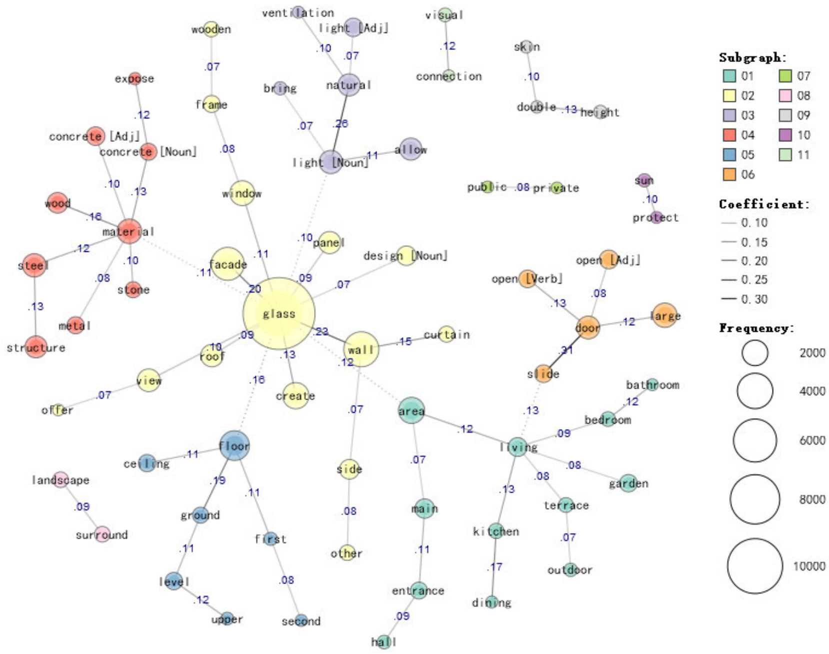

Figure 6. Lexical text co-occurrence network based on "glass".

Although "steel" forms the material foundation of modern architecture alongside "concrete" and "glass", its recent focus regarding lexical co-occurrence networks has diverged from the latter two (Figure 7). In the lexical co-occurrence network related to "steel", the presence of "locate-architect" (Subgraph 09) and "frame-view" (Subgraph 10) indicates that the application of steel in architectural design is gradually shifting from concealed and industrialized to visible and localized. This shift is directly related to how materials are presented. In modern architectural design, "steel" is frequently used in conjunction with "concrete" as reinforced concrete. However, advancements in green technology and the emergence of local issues have created more opportunities for "steel" to be prominently featured as an exposed structural element [50]. Architectural attention to "steel" overlaps somewhat with that given to "concrete" and "glass", particularly in material properties (Subgraph 01), material interactions (Subgraph 03), and material presentation in horizontal building components (Subgraph 02). Furthermore, the structural properties of "steel" are further emphasized within the primary clusters. In terms of the frequency of keywords appearing, nearly half of the text units mention both "steel" and "structure" simultaneously, with a coefficient reaching 0.27, which is the highest co-occurrence rate in the text network. This differs from the co-occurrence subgraph centered on "concrete" and "glass", which is relatively more focused on spatial functions ("wall") rather than the architectural structure composed of materials. The word group derived from "structure" represents the structural system composed of a "truss", "beam", "column", and "roof" (Subgraph 04). In addition, most of the core words that constitute Subgraph 06 are related to the different forms of steel. Although the overall text co-occurrence coefficient is relatively low (0.08), it underscores the emergence of utilizing steel processed in various ways to articulate design intent, which reflects the performance of steel in architectural design indirectly.

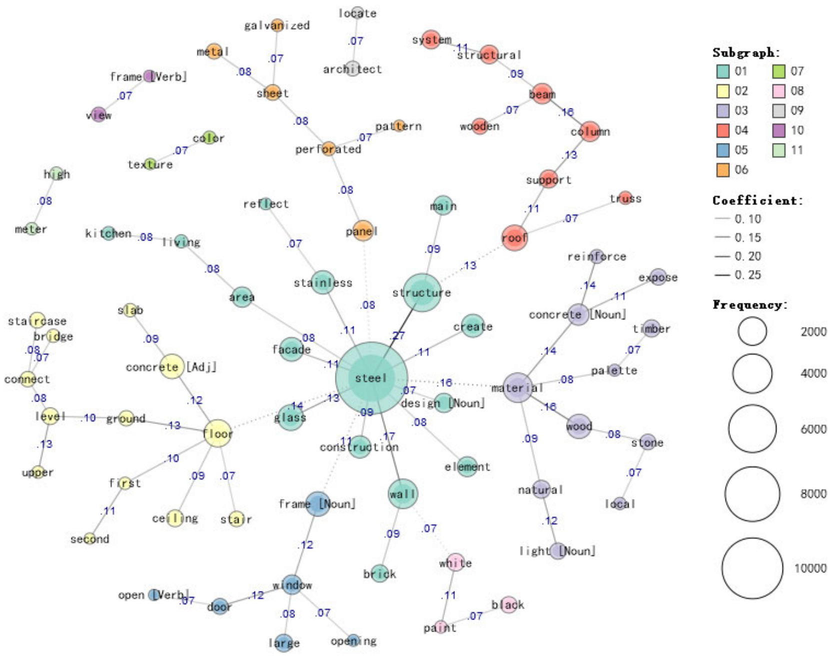

Figure 7. Lexical text co-occurrence network based on "steel".

3.4. *Wood and Timber*

Over the past decade, with the development of wood MPF, a renaissance in wood architecture has emerged, rivaling concrete construction in architectural design [51]. The wood architecture offers unparalleled environmental and aesthetic benefits and is of growing importance for sustainable development and green design [52]. From the co-occurrence networks related to "wood" and "timber" (Figures 8 and 9), in addition to discussions about structure and spatial layout [49], both focus more on the spatial experience and architectural environment created by wood in terms of material properties (wood Subgraph 02 and timber Subgraph 01) and material interactions (wood Subgraph 03 and timber Subgraph 02). Within the lexical co-occurrence networks, the sustainability of "wood" and "timber" is achieved through their intrinsic link with "natural". While "natural" and "light" constitute a common collocation across various material lexical co-occurrence networks, it is noteworthy that, in contrast to synthetic materials such as concrete, brick, and glass, both "wood" and "timber" exhibit higher coefficients with "natural" (0.15 and 0.14, respectively). These figures surpass the coefficients observed between "natural" and "light" (0.11 and 0.12, respectively), indicating that, compared to the environmental attribute of natural light, the natural qualities of "wood" and "timber" attract greater attention and appreciation in architectural design. The inherent naturalness of the materials is precisely one of the significant advantages of wood as a sustainable building material [53]. From an aesthetic perspective of materials, the lexical co-occurrence networks clearly establish the connections between color, texture, and the warmth experience. Concurrently, these focal points exhibit a more intricate connection within the wooden material system, as opposed to the distinct categorical presence observed in the co-occurrence patterns of modern building material vocabularies. It indicates that compared to concrete, wood displays more hybrid properties in its expressions. Moreover, in the facade openings of buildings, the performance of wood is similar to that of "steel". Both materials are typically associated with the opening components and the frame rather than the facade itself. This signifies that within architectural facade openings, the structural functionality of wood material outweighs its capacity as a decorative expression.

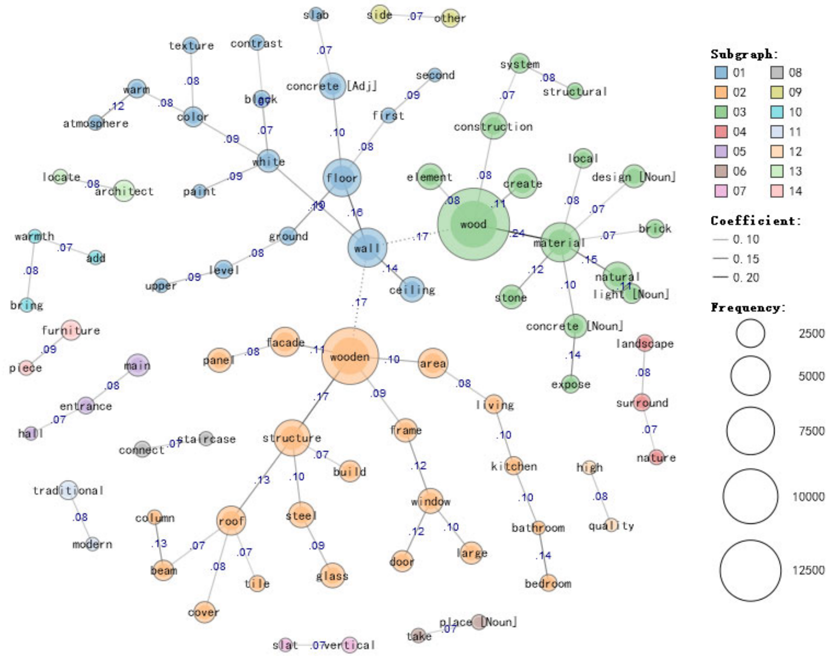

Figure 8. Lexical text co-occurrence network based on "wood".

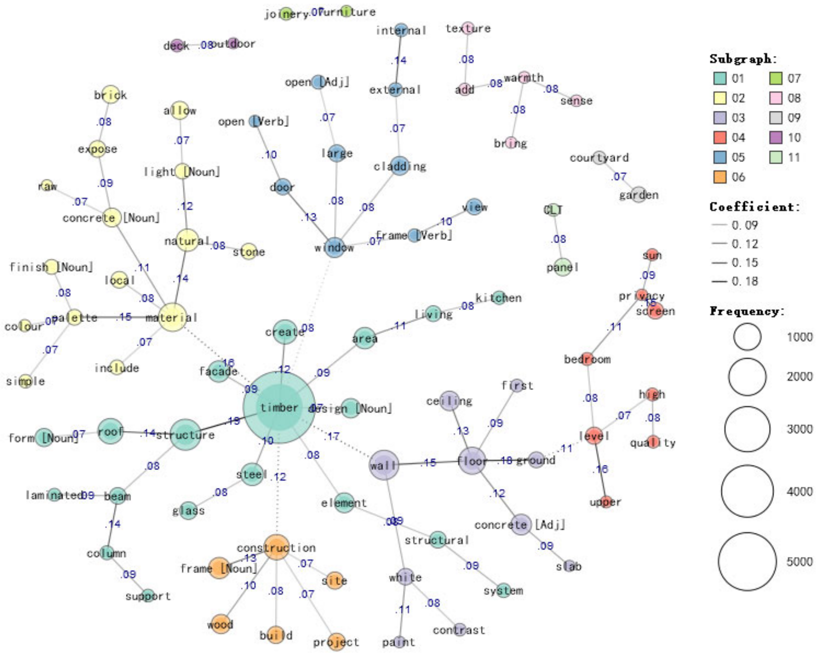

Figure 9. Lexical text co-occurrence network based on "timber".

With the material presentation in components (wood Subgraph 01 and timber Subgraph 03), wood has a broader range of applications compared to modern building materials, extending beyond horizontal components ("floor" and "ceiling") to vertical components ("wall"), which is a significant focus in discussions of architectural design [54]. This shift in focus suggests that architectural design's emphasis on wood has gradually moved from its functionality to the spatial experience it provides. Additionally, the relationship between wood and concrete in layered construction on the ground and the connection between "paint" and wood on walls clearly conceal the material's nature and move towards a revival of decoration [3]. This phenomenon can also be observed through terms related to "furniture". In addition to uses in architecture, wood materials are of interest at the smaller scale of furniture and other components, such as "staircase" and "furniture".

3.5. Brick, Stone, and Metal

As typical representatives of traditional local materials, bricks, stone, and metal exhibit different characteristics in architectural design across various regions and cultural backgrounds [5]. The expression of local materials often focuses on how they reflect regional symbols and cultural heritage [55], contrasting sharply with industrialized building materials that emphasize general applicability and functionality [56]. This distinction is evident in the co-occurrence networks of terms related to "brick", "stone", and "metal".

In contrast to modern building materials, the topic with "material" as the core word in the co-occurrence network of the brick does not only reflect the interaction of materials (Figure 10). On the contrary, the color and texture of the brick can directly affect the expression of architectural design style through the material itself (Subgraph 01) [57]. In addition, the interaction of wood and bricks developed into a concern in the physical environment of architecture (Subgraph 04), which affects the architectural environment, such as "light" and "ventilation". There is also apparent emphasis placed on the "thermal-mass" of the brick materials from scattered word groups. This indicates that energy efficiency has become a key focus in the design and application of brick materials [58]. Furthermore, in the presentation of brick materials in vertical components, two branches emerge: "wall" and "facade" (Subgraph 02). This suggests that, compared to modern building materials and wood, the emphasis on brick materials in architectural design is entirely on the spatial experience. Within the branch centered on "wall", two further dimensions emerge: "floor" (Subgraphs 03 and 05) and "structure" (Subgraph 07). This signifies the intimate connections between brick walls and other components, exemplified by "concrete floor" and "steel structure". In comparison to the coefficient of 0.31 between "wall" and "brick", the co-occurrence coefficient between "white-paint" and "wall" is notably lower, amounting to just 0.07. This significant decrease indicates that the depiction of brick walls in architectural design has undergone a notable transformation, shifting from a tendency to conceal the material characteristics to one where they are prominently displayed. Moreover, the implication of "white-paint" in concealing the materiality [59] also indicates that brick materials rely on being integrated with other building materials to form a complete spatial system. In the core branch focusing on facades, the relationship between the architectural interface and openings formed by brick materials is a primary concern in architectural design.

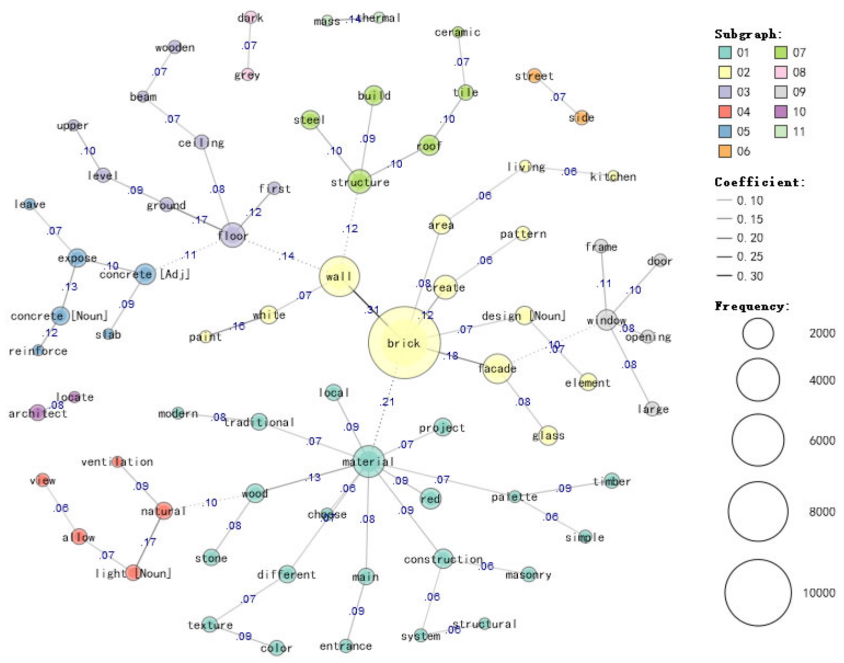

Figure 10. Lexical text co-occurrence network based on "brick".

The co-occurrence network analysis of "stone" shows significant similarities with that of "brick" (Figure 11), with "material" being the central theme in their interaction (Subgraph 01). As natural materials, wood and stone are most closely related [60], with coefficients of 0.24 and 0.21 for "materials", respectively. In contrast to the sustainability associated with the naturalness of wood, the naturalness of stone is more often discussed in the context of architectural locality [61], as evidenced by the coefficient of 0.12 between "local" and "materials". The interaction of stone with other materials in architectural design also implies that the visual appearance of stone enhances the overall spatial perception and experience of the design [62]. Similar to the presentation of "brick", the application of stone in vertical components is divided into "wall" and "facade", with the emphasis of "facade" closely related to facade openings. Additionally, the texture and color of stone have a close relationship with architectural style, as emphasized in discussions on "white marble" and "architectural form".

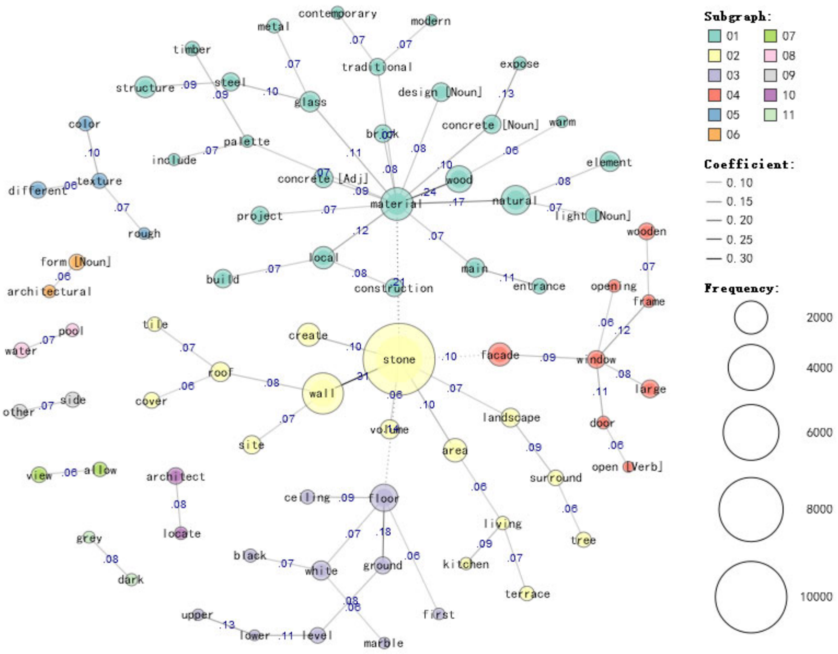

Figure 11. Lexical text co-occurrence network based on "stone".

In view of the similarity of inherent properties of materials, most of the topics in the co-occurrence network of "metal" are consistent with those of "steel" (Figure 12). In terms of the connectivity within the material characteristic word clusters (Subgraph 01), both "metal" and "steel" exhibit a complex interplay of word clusters, making it difficult to generalize based solely on word categories. However, as is evident from the sheet and panel branches, metal is of greater interest in material processing than steel. Therefore, the various metal forms created through different processing techniques serve as a crucial element in architectural design. There is often a greater focus on the metal processing techniques than on the classification of the material itself [63]. For example, the term "aluminum" is more frequently associated with "plate" as a separate word cluster, rather than being grouped under the broader category of "metal". Simultaneously, the application of metal in architectural structure also exhibits two main branches (Subgraph 02): one involves structural components combined with concrete and the other relates to architectural facade openings with steel frames, representing the focus on composite materials and pure metal materials in architectural components. In the group of material interactions (Subgraph 03), the connection between metal and both concrete and wood dominates, indicating that metal frequently serves as an auxiliary material to wood or concrete in its interactions with other materials.

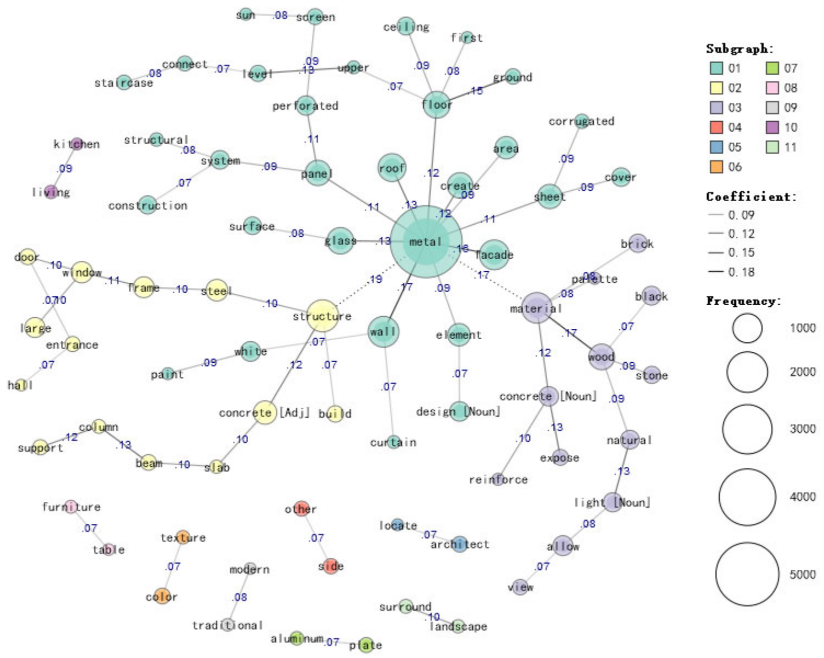

Figure 12. Lexical text co-occurrence network based on "metal".

4. Cases of Study Program

After sorting out the key points of representative materials used in architectural design, the study investigated several typical cases as the research object, which verified the features of some materials used in architectural design.

The LocHal library is a cultural piece of architecture located in Tilburg, Netherlands, which was previously a railway locomotive depot before its transformation [64]. The project was designed and constructed during 2014–2019. Steel, glass, and concrete were the main materials used in the project. Consistent with the performance of "steel" in the co-occurrence network (Subgraph 04), the structural system consisting of a steel truss roof, columns, and beams provides an imposing and lightweight scene, which is distinct from the heavy structure of typical libraries made of concrete. This lightweight style is also manifested in the building's exterior skin, which comprises steel frames and glass, resonating with the findings from the co-occurrence network analysis of "steel" (Subgraph 05) and "glass" (Subgraphs 02 and 03). Due to the aim of revitalizing industrial heritage, the architectural design has been imbued with dual purposes: renovation and preservation. The design subtly retains the corroded appearance of some unpainted steel columns, emphasizing their status as part of the industrial heritage. In contrast, the other steel columns in the design are concealed by additional plates to fulfill the renovation purpose. This is consistent with the analysis of the "steel" co-occurrence network in this study, which underscores that as locality emerges as a pivotal theme in architectural design, the focus on steel materials is gradually transitioning from concealed to visible. Wood was mostly used as interior decoration or furniture in this project, which was attached to the surface of concrete or steel, creating a decorative style comprising a concrete/steel base and wood surface. This confirms the transformation of wood from functional to decorative in architectural design. The decorative style harmonizes the cold and rough texture of steel and represents the functional transformation from industrial to cultural architecture in the space. Meanwhile, the diverse color attributes of different materials enrich the visual experience of the library, which aligns with the emphasis placed on concrete (Subgraph 09), steel (Subgraph 07), and wood (Subgraph 01) in the material lexical co-occurrence network.

Home of Hand-craft Experiments is a residential project located in Beijing, China, which was completed in 2020 [65]. The project made use of almost all the materials discussed in this study. The design case integrates the characteristics of various materials onto the same wall, expressing the material interactions through different wall facets. This approach resonates with the central focus of this study. On the facade facing the living room, the wall showcases the color interaction between concrete and red brick. The concrete "structure" and the red brick "wall" are the most significant elements in their material lexical co-occurrence network. Distinct from mere color differentiation, the rough texture of both concrete and red brick is deliberately retained on the surface, as a response to the "hand-craft experiments" design theme. On the other facade facing the living room, the stone used as cladding material shares the same color as the concrete. Meanwhile, the smooth texture of the stone forms a stark contrast with the rough texture of the concrete. While texture and color often coexist within the material lexical co-occurrence networks of concrete (Subgraph 09), red brick (Subgraph 01), and stone (Subgraph 05), distinct material combinations exhibit varied material interactions, ultimately shaping the diverse visual identities of building facades. As a non-structural, transparent partition within interiors, glass ensures the functional partitioning of space while introducing outdoor light and facilitating line-of-sight penetration simultaneously. This directly corresponds to the analytical outcomes of Subgraph 03 and Subgraph 01 within the glass lexical co-occurrence network. The interaction between the glass wall and the wooden window creates a movable opening on the solid wall, and the opaque opening on the transparent wall reverses the conventional concept of architectural transparency. The color and texture of the wood in this project are notable. Different types of functional furniture differentiate color and texture for wood use, highlighting the logic behind the choice of wood in space, such as the window with a light timber texture, the round table with a dark wood texture, and cabinets with a light plywood texture. This also addresses the matter of crafting differentiated spatial elements within the material lexical co-occurrence network of architectural design text, specifically pertaining to the concepts of "wood" and "timber".

5. Conclusions

The study analyzed the application of various building materials in architectural design through lexical co-occurrence networks, utilizing data from 35,656 actual projects on the architectural media over the past decade. The conclusions drawn from this analysis are as follows:

(1) Over the past ten years, the MPF of materials in architectural design has increased by 27.2%, reaching 89.6%, validating a gradual return to materiality in architectural design practice and countering the previously dominant trend towards mere visualization. From the analysis of commonalities in various materials' co-occurrence networks, material characteristics, interactions between materials, and the presentation of architectural components emerge as three universal focal points in material applications in architectural design.

(2) In architectural design, the application of wood and concrete always maintains a primary position, with their respective MPFs in 2020 reaching 73.7% and 62.9%, nearly twice that of other materials. Beyond the consistent emphasis on structural functionality, the analysis of coefficients in lexical co-occurrence networks reveals that green design issues related to sustainability and energy consumption have also emerged as pivotal concerns in architectural design practices.

(3) Over the past decade, the MPFs of brick and stone have grown rapidly, with respective increases of 24.3% and 11.8%. As evidenced by text network co-occurrence coefficients, brick and stone primarily respond to the locality and style of architectural design by emphasizing their inherent texture and color, thereby enhancing the spatial perception and experience within the designs.

Contrary to traditional case studies confined to small samples, this research systematically evaluates the application trends of materials in architectural design, effectively circumventing the potential limitations of conclusions arising from sample selection bias. While offering some insights into the use of materials in architectural design, this study acknowledges its limitations. Due to the limitations in the length of the paper, we have selected only a single architectural media outlet as the source of data for our text analysis, and the settings and preferences of this outlet may have a certain impact on the conclusions. Notwithstanding these limitations, this study nevertheless lays the groundwork for quantitative research on the influence of building materials on architectural design. Furthermore, it illuminates current trends and preferences in material application within architectural design, thereby empowering architects to make more informed decisions in their material selection.

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