A Color-Material Network of Chairs through Materials and Colors

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Abstract

Background Choice of color, material, and finishing (CMF) has been essential for styling and product design. Empirical studies showed interaction effects of the three ranges and revealed that particular CMF combinations are relevant than a choice of optimal color, material, and finishing independently. We choose a chair for the target product as a preliminary approach to observe color and material characteristics of the product. We aim to analyze color and material relation using the metrics of social network analysis.

Methods We visualized a network of chair components by their colors and materials combination on 1,000 historically meaningful chairs in design history and identified visually dominant components and profiled each in terms of color (14 categories) and material (11 types), called "CM". With the data set, we facilitated UCINET software to examine the network characteristics such as Size, Density, Centralization, and Subgroup. Also, we composed an interactive network using R to ease navigation and to offer dynamic interfaces. To exploit the experiential and practical values of our network, we conducted a focus group interview (FGI) with seven designers.

Results This study offers a visualization of color and material connection over a CM unit network. UCINET showed that CM network's density was 26.9% and centralization was 6.9%, and one subgroup was formed. FGI feedback showed that the CM network was intuitively informative, brought unexpected surprises, and the possibility of exploring design style.

Conclusions This study presents the chair network in a new way of data archiving for color and material information. We expect the visualization of the connectivity among the products through colors and materials to inspire aesthetic inspiration.

Keywords Color Material Finishing (CMF), Network Analysis, Material, Chairs

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1. Introduction

1. 1. Background

In the history of art and craft, the choice of color, material, and finishing (CMF hereafter) has been essential for styling. Subsequently, designers deliberately select the material and the color to serve the best of their design concept (Pedgley, 2016; Kim, 2014). It is one of the creative challenges to make a unique experience through different combination that product designers face (Hassenzahl, 2010). However, a systematic approach to material selection is vulnerable. It is designers' responsibility to select the materials and few tools were developed (Ramalhete, 2010).

Designers desire a tool that can provide some opportunities for creative material choices (Pedgley, 2014). In a conventional procedure of product design, CMF design is in a relatively later phase of the design process. Differently from the former approaches, Ashby (2013) proposed a new product design process that propagated a sporadic campaign to urge CMF-oriented design works on current design practice. Efforts in such circumstances have been made to archive the CMF samples in both tangible and intangible manners.

Across disciplines, studies have mainly dealt with archiving and collecting knowledge on CMF and methods for proper visualization. Regarding the color, the subjective judgments of single colors have been widely investigated, and distinctive colors were often associated with categories of emotions. In 1981, Kobayashi (1981) introduced the Color Image Scale where the color combinations were identified and grouped according to their styles. The study suggested that the interaction between two or more colors was highly supportive in visualizing a target style. Similar studies and libraries were proposed to assist designers' color choice because the number of color combinations increases exponentially. Also, *ColorAdobe* (2019) and *ColourLovers* (2020) are crowdsourced online platforms where users can create and upload color schemes, which have color combinations made up of five color patches. The color schemes are labeled with creative names, and other users can vote for them. Kim and Suk (2015) tried to identify harmonious color combinations within a set of color schemes. In this study, nearly 7,000 color schemes were collected and applied to network analysis. The network analysis supported a quick and easy visualization of color data through a closeness centrality measure. The interaction effect was more intensive and dynamic than what a single color could have appealed in the color combinations and their style associations.

Particularly some material scientists and engineers have been involved in building knowledge of material. They focused on archiving and managing the technical information about different material. For example, *DesignInsite* is a materials information database with a total of 120 items grouped into ten hierarchically organized groups (see Figure 1). The database included unique materials to trigger creative inventions. Also, Rao (2006) tried to adopt a network structure to create the materials based on their relationship with others. This study focused on the material properties and their interactions. *Material ConneXion* (1997) is a commercial service of the materials library active worldwide where designers can access information. This service publishes the database in both digital and paper-based media periodically. Meanwhile, relatively less highlighted than color or material, the finishing aspect of the CMF has been investigated intensively. Surface characteristics that are closely related to the tactile experience were studied in various disciplines. In design practice, the glossy level is one of the representative aspects of the finishing (Baek, 2015; Na, 2012).

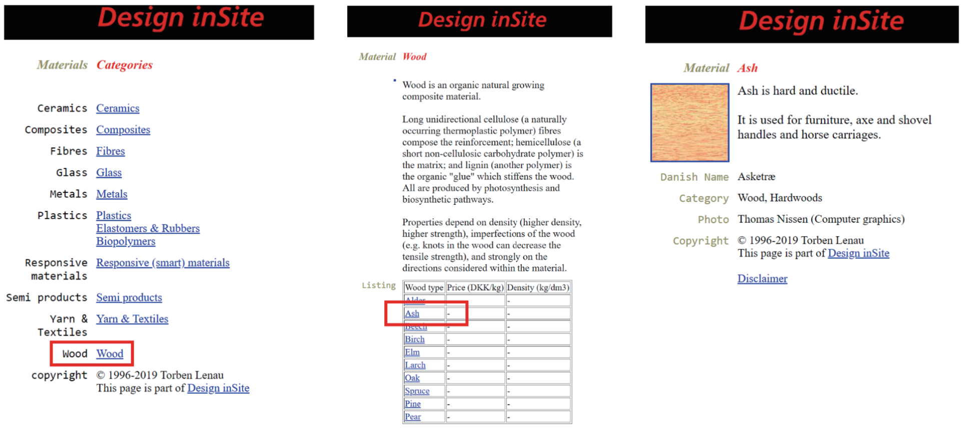

Figure 1 Wepage of *Design inSite*

Moreover, empirical studies have shown interaction effects of three ranges within CMF. They revealed that particular combinations are more relevant than a choice of optimal color, material, and finishing independently. In the product design process, certain CMF combinations, such as glossy red leather or matt black plastic were treated nominally. Hence, when designers decide and design the CMF of the product, the interaction between color and material is critical. Especially, by focusing on the material combination, researchers emphasized inspiration through applying materials to the product in an unexpected manner (Bae, 2017; Pedgley, 2014; Van, 2014).

1. 2. Purpose and Overall Process

1. 2. 1. Purpose

In this study, we aim to observe the color and material characteristics of a product and choose chairs as the target products for a preliminary approach. Design chair is the most basic product in design field. By selecting design chairs as a main subject to analyze CMF, we implemented to respect quality and completeness of design chairs and the value of chairs in the design discipline. Among CMF, we focused on the first two as they are more distinctive in visualization through digital images. In particular, when defining M element, a typical pairing combination between material and finishing is used together (e.g., metal with shiny finishing).

1. 2. 2. Overall Process

As an initial work of the network analysis of product design components, we defined CM to stand for the colored material that consists of a product. As an initial stage, we did not include finishing of the CMF and attempted to relate various chairs through their prevailing units. To identify the relationship among the colors and materials using the network analysis, we collected CM information of chairs and examined them. Then, we expanded the material and color information across a set of chairs. We aimed to analyze the CM connection using the metrics of network analysis focused on the chairs accordingly. After the analysis, we proceeded focus group interview (FGI) to explore practical values of our network.

2. Method

2. 1. Method for Creating CM Network

2. 1. 1. Collecting Chair Information and Creating CM Data Set

For the data collection, we referred to the book, 1000 chairs (Fiell 2015), which describes both the physical and contextual features. Out of the 1000 chairs described, we deliberately included only 770 chairs since the excluded 230 were either duplicates or simply not actual chairs. Some chairs described were blueprints or sketches while others had insufficient information about the materials of the chairs. Regarding the 770 chairs, we identified the CM attributes and then registered them for each chair. Instead of describing all the detailed substances, we considered perceptually dominant components, minimizing the number of alternatives while maintaining diversity.

Labelling the CM, we referred to 3D modeling software to learn how the rendering library sorted color and material (Bae 2015; Kim 2021). We began with the 11 basic colors and then added three additional colors (gold, chrome, transparent) while labeling color data manually, resulting in a total of 14 colors. It is presented in [Table 1]. Regarding material labeling, we considered 11 types for the material types, thus, and we intended to generate 154 CMs as the combinations of 14 colors and 11 materials. However, there were some irrelevant combinations such as transparent wood, and chrome wood, and thus, we admit the irrelevant CMs to be excluded in the analysis.

Table 1 Code for material and color elements

Element	Code
Color Elements	black, blue, brown, chrome, gold, gray, green, orange, pink, purple, red, transparent, transparent, white, yellow
Material Elements	fabric, fur, glass, wood, latex, leather, metal, paper, plastic, stone, vinyl

2. 1. 2. Adopting Social Network to Visualize the CM Relationship of Chairs

We adopted the Network Analysis to visualize the relationship among CM dataset from various chairs. For example, Mies van der Rohe’s Barcelona Chair (1929) is made of black leather and chrome metal, which can be translated into black leather CM and chrome metal CM as node and Barcelona Chair is expressed as an edge, as presented in Figure 2. The network analysis is utilized to visualize a complex interaction among items or components based on the quantified relationship in a pairwise manner. The Social Network Analysis (SNA hereafter) is the known paradigm that has achieved an intuitively visualized communication by illustrating the people or social units with the linkage in-between.

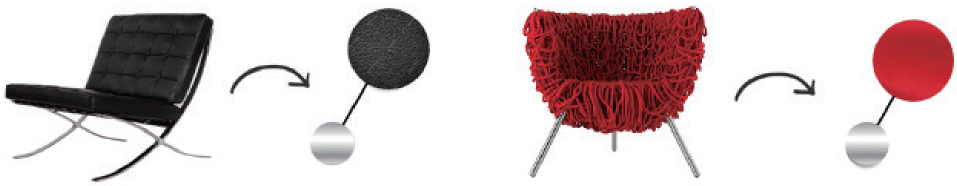

Figure 2 CM of Barcelona Chair (left) and Vermelha chair (right) are translated into a network form. Linkage represents each chair and node size is proportional to the frequency of CM collected.

To have adequate data for SNA, we translated the CM data set pair-wisely. The elements were nodes or vertices in the network analysis, while the paired relationships were linkages or edges. For example, Toshiyuki Kita's Wink Chair (1980) was registered with four nodes and thus six edges were counted (4 * 3 / 2). However, regarding chairs comprising one were excluded from the network data set since edge information was not eligible. Philippe Starck's Louis Ghost Chair (1987) was an example, as it is composed of transparent plastic only. Also, Alessandro Mendini's Proust Chair (1978) was beyond the current CM Data Set because the chair was composed of patterned fabric which is hard to define its CM.

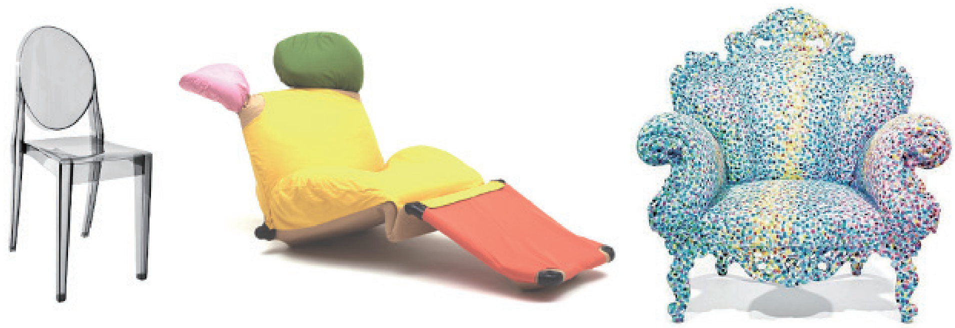

Figure 3 Wink Chair (left) was included in CM having four nodes and six edges. However, chairs made out of single material, such as Ghost Chair (center) were excluded, because the link information was not eligible. Chairs with complex patterns were excluded in current CM Data Set. Proust (right) is an example.

2. 1. 3. Visualization of an Interactive Network with R Studio

Although the UCINET provided quantitative metrics about the network, we attempted to make it more self-explanatory and inviting for active participation. We composed an interactive network based on the data set using an open-source programming language R (version 3.6). Specifically, we utilized the libraries including igraph, ggnet2, and ndtv to build the network data structure and visualize it. The ndtv library enabled us to create an interactive network in that edges were hyperlinked to the corresponding chair images. Also, this interactive network published a web document in that users can explore the Edges and the hyperlinked chairs. If requested, the visualization is easily adjusted by manipulating color codes, the logic of sizing and thickness.

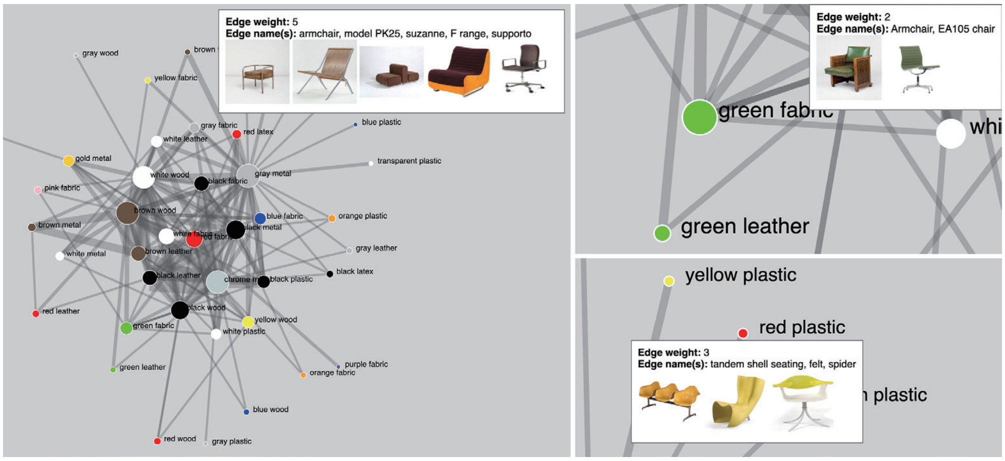

Figure 4 CM Network visualized through ggnet library in R. An mouseover action shows the corresponding chairs from the Data Set. The node size and edge thickness describe the frequency of each CM

In Figure 4, a network with a minimum edge size of 2 is visualized, which means chairs are comprised of two CM combinations. The node diameter and edge thickness are in proportion to the frequency of CMs and connections. When an edge is selected, the corresponding chair images are loaded. For example, five chairs are loaded when the edge between brown fabric and grey metal is clicked. The edge between green leather and chrome metal retrieves two chairs. The edge between yellow plastic and grey metal retrieves three chairs. An active network is available at https://color.kaist.ac.kr/wp-content/dataVisualization/chairs/. The interactive network was used in Focus Group Interview to explore its usefulness.

2. 2. Process of Focus Group Interview

We recruited seven designers with industry practice. Since this study aims at the opportunity of CMF exploration, the interview subjects were cast to various expertise such as automotive, furniture, graphics, home appliances, lighting, and textile designs. They were four men and three women. Average age was 30.71 years old, and the standard deviation was 7.13.

During the FGI, we guided designers to explore the interactive CM network visualized on the web browsers for 15 minutes. Designers were not given any specific technological instructions on why the network is developed or how to use it. After it, for 45 minutes, we carried out a semi-structured interview asking “How unique was the experience?”, “What do you think about its application or possible development direction?”, and “What needs to be improved in the current state of this network?”. We transcript the answers and feedback and clustered the insightful contents into four aspects.

3. Result

3. 1. Observation of CM unit Network with 582 Chairs

The most frequently used CM unit was brown wood (i.e. natural wood), which is used in 171 chairs. White wood (143 times) was the second, followed by chrome metal (139 times) and grey metal (119 times). In the following section, we restructured the data set to describe the CM combination within a chair.

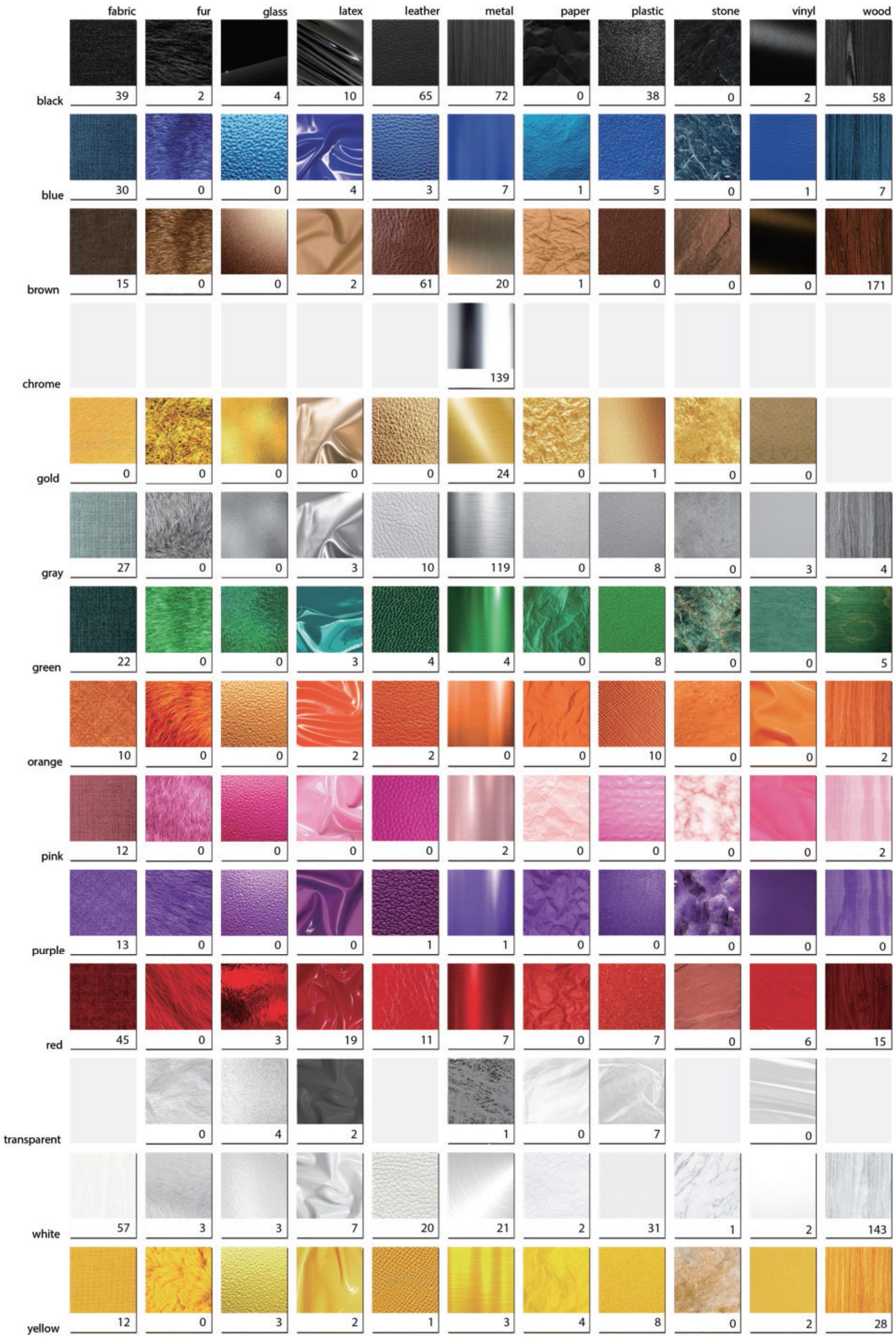

Figure 5 A swatch samples of 139 CMs, which is initially comprised of 14 color categories and 11 material types. Irrelevant CMs are 15 which remain empty. In addition, the caption numbers refer the CM frequency. For example, the brown wood denoted with 171 indicates that brown wood was found over 171 chairs.

[Figure 5] is a graph of CM unit image and collected frequency of design chair case. The graph shows all possible CM units as image and the number below the image as chair network case.

We found 582 chairs with more than one CM and identified 985 edges in total. Among the edges, two edges were highly frequent. One is an edge between black leather and chrome metal. The other edge is a combination of brown wood and brown leather. In this manner, the quantitative analysis of the network was an investigation into the 985 edges that link 86 nodes extracted from 582 chairs in total. We loaded the data set in the UCINET to perform the statistical analysis of the network. We loaded the data set in UCINET and performed a series of quantitative analyses as follows.

3. 2. Network Analysis result with Pajek

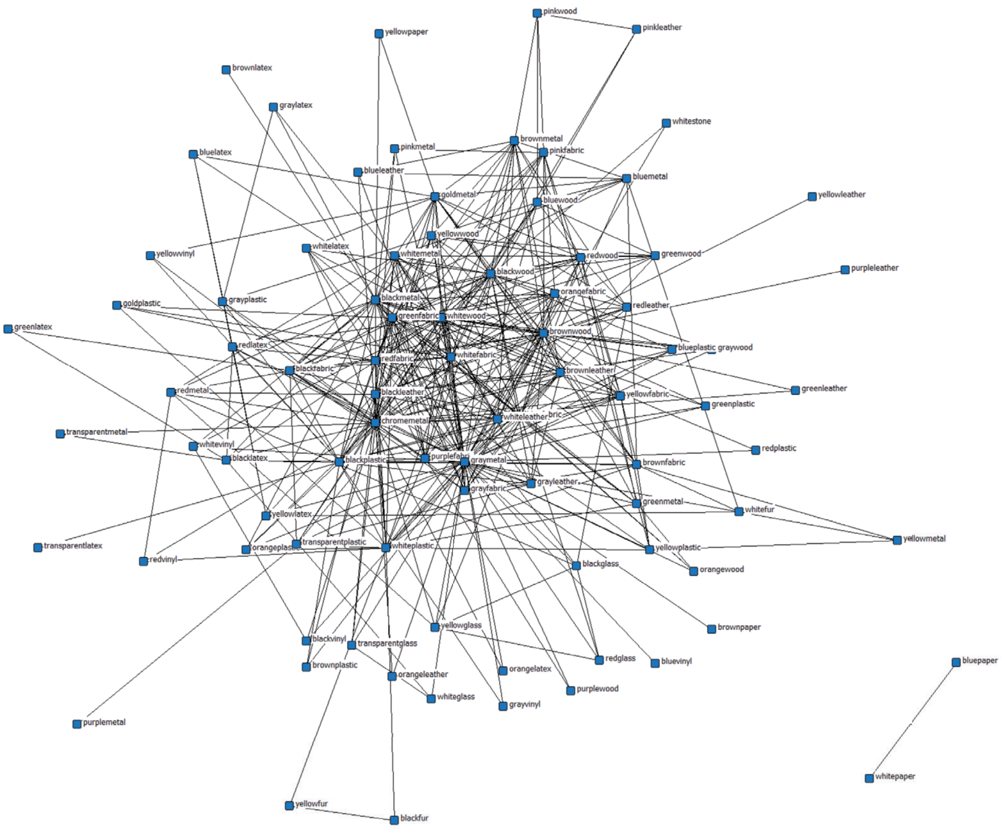

Figure 6 CM Network visualized through Pajek, in UCINET. Size of nodes and thickness of edge are homogeneous, which is not easy to figure out at one glance.

Table 2 Metrics of quantitative analysis of CM network

Factor	Value
Size	7310
Density	26.9%
Centralization	6.9%
Subgroup	1

We loaded the data set in UCINET to perform a series of quantitative analysis and visualized through Pajek, which is presented in [Figure 6]. Here is the result analyzed through UCINET in [Table 2]. At a network level, we observed size, density, and centralization of the network. The estimated network size was 7310 (86 * 85). This includes all possible and directional connections in this network. Our study disregarded the direction. Conventionally, the size is estimated by multiplying the total size of nodes by total nodes minus 1.

Estimated density by applying unidirectional size estimation was 0.27. Density infers the diffusing speed of information among the nodes. In general, density value of more than 0.10 is a high figure in social science. The remarkable difference mainly lies in the collection of nodes. If the types of color and materials are more elaborate, the density might decrease since the denominator increases.

Centralization was 6.9%. This is much lower than the centrality scores in other network analysis, that is over 25.0%. Centralization is reciprocal to the number of edges. Thus, we consider that such comparison with studies in a similar research context is more relevant than social science studies.

Last, subgroup intends to cluster nodes into small networks based on latent trends. However, the UCINET failed to sub-divide the network as indicating that their network is a single group as a whole. With both low centralization and a single subgroup, the network is tolerant and intertwined with diverse CMs.

3. 3. Result of Focus Group Interview Feedback

3. 3. 1. Easy Review of Material Archive: "The network tells me that ..."

Designers were able to identify the CM used in chairs through the network. P3 said, "Interesting because it is a different way of information from a book of". P2 mentioned that "I can tell that the wood used to be classic, and any materials with black, gray, and white were loved within the various design". With this network, now he can consider designs in terms of material. From these comments, we want to extol that this network is most useful when you want to gain an intuitive understanding of CM attributes within a material archive perspective.

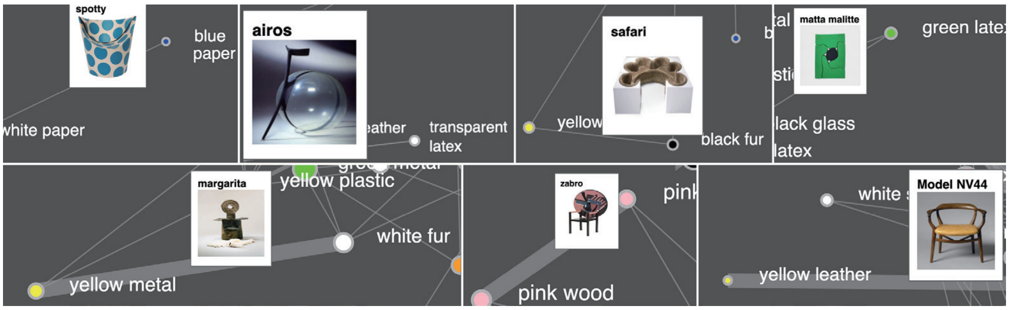

Figure 7 Designers showed a particular interest in the isolated CMs and the chairs thereof. Often, those chairs were found absurd but at the same time inspired users. Each of the above seven chair images is retrieved real-time, when corresponding edge is clicked.

3. 3. 2. Material Inspiration Opportunity: "Unexpectedly though, this reminds me of ..."

Also, P1 and P4 mentioned "inspiration opportunity". They said, "Before clicking the edge between transparent plastic and purple glass, hardly imagine its combination and its final shape", and "It was amazing especially marginal edges containing only one or two designs. I did not expect this kind of amusement". From [Figure 7], we got a new opportunity for the inspiration area. P5 said, "This material combination graph helps me to see what designs have been made".

3. 3. 3. Miscellaneous Applications: "Oh, I have more ideas!"

Since interviewed designers were not guided with any rules or regulations, they showed us their variable applications. In the case of P3, he said by clicking on the combination of materials to check the design work. He got what style has been made with this combination of materials. He explained that a certain combination of materials could be expressed in a specific style.

P5 proposed an idea of making a design work archive. Because the network is focused on color and material properties only, the data set can be utilized as a benchmark of existing cases or an alternative allocation of given materials of product design. P4 also commented that adding other chairs made after the 2000s or product samples of look-book images or furniture fairs in Milan, Italy. He mentioned 'new materials' as a new category from the material aspect, like fluids and living organisms for future design. These comments are reviewed for further development on this study.

3. 3. 4. Interface Needs to be Upgraded: "It would be better, if ..."

However, there are some improvements required. First, from both P5 and P6 interviews, we realized there are some usability issues. "It was hard to select the edge". "Distance between each node is too short and lines are too thin". Second, P2 wants some filtering function, which allows a pool of chairs from a specific era or in specific CMs. He said, "If I can see those chairs of 'soft' factor through filtering, it could also be very useful".

4. Discussion

4. 1. CM Data Set and Value Exploration

Kim (2020) tried a network method to design chairs to visualize color and material factors. However, the goal of the study was to consider intuitive identification and observation of color and material of chair. Although visualizing the network was an explorative try to prompt the inspiration process as CMF, there is a lack of analytical approaches.

Our goal was not limited to the color and material relationship found in the network but also to achieve the CM information differently. We pursued organizing and presenting images based on the reasoning behind, and the commonly used CMs and their connections are the good rationales why those images are clustered together.

The purpose of our network is to inspire designers in design practices to consider materials that are new or unknown to them. Realizing the new possibilities in an early stage of the development process enables new and innovative products to emerge. To realize the connected relationship between CMs among many chairs, we facilitated the network analysis, and it is a new approach to archive the CMF information. Once a particular type of CM is fixed, it is easier for designers to find detailed technical information in the digital or the analog form of the library. As mentioned in the interview, such unexpected grouping inspired designers from different domain as they never considered those chairs on a common-base.

This discovery of which difference between the design work and its expectation can be explained as the inspiration opportunity aspect, which is consistent with Ludden (2012), who argued that inspiration can be stimulated by giving designers surprises through unexpected experiences in the context of material experience (Karana, 2008; Ludden, 2012).

4. 2. Network Analysis and User Benefits

We utilized the UCINET, and generated quantitative features about our data set, and analyzed the graph in the perspective of network analysis. Regarding the results, we tried to interpret them in comparison with those from conventional network studies. Finally, our data set consisted of pairwise connection (i.e., edge) between CMs (i.e., nodes), were denser, less centralized, and had indistinguishable subgroups. However, the metric data are drastically varying depending on how we declare the structure of the data set, and there has been no previous reference yet to follow.

5. Conclusion

5. 1. Main Implications

In this study, color and material network was presented a new way of archiving color and material information which was intuitively reviewing itself. We identified the chairs into their major components and profiled the color and material as CM. To make the data set, we registered the CMs of chairs and composed the network based on the binary connections among CMs. UCINET software was selected to perform a quantitative analysis. After this analysis, the network was visualized with R (version 3.6) and made the network interactive to enable users to retrieve corresponding chair images. We recruited designers to collect the feedback while using the interactive network presented in our research. Their opinions were on easy review of the material archive, inspirational unexpectedness, spin-off services, and improvement of the interface.

5. 2. Challenges and Opportunities

We sorted colors and materials based on 3D rendering software and labeled CMs manually, which decide how the data set is constructed and directly affect how the result is realized. Deeper academic considerations are necessary for color category.

Besides, there is room for improvement on M element, which is restricted to typical combination of material and finishing. Conventionally, finishing has been associated with material because it can express materials as well. Also, as mentioned in section 2.1.2., we have not yet dealt with complex colors and complex materials. Chairs with complex patterns or ornaments were simplified excessively during the CM translation into the data set.

CM network should be improved more straightforward navigation and better interface. The current version looks somewhat chaotic that users may lose their interest in using it further longer. Continuous improvement and implementation are anticipated to mature the study to support practical use and knowledge contribution.

5. 3. Approach for Design Research

Expanding the data set across the various product genres could lay a positive impact on the inspiring experience. We expect that visualization of the connectivity among the products through colors and materials to inspire aesthetic inspiration. This study shows relationship between CMF components in both analytical and intuitive ways. The method adopting the network analysis to analyze and visualize can be highly utilized as an explorative approach in fields where knowledge accumulation through experience is inevitable, such as design education and product design.

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