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A creative industrial design framework of the taxonomy for Chinese indigenous materials and relevant crafts

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Industrial designers have a need to acquire knowledge related to physical materials and undertake activities such as materials selection and materials-driven creative design. Chinese indigenous materials (CIMs) and relevant crafts are identified as a significant but currently untapped resource for designers. Existing research lacks systematic organization and classification for this rich resource making it difficult to develop an online materials database for creative design. To enable industrial designers to develop an understanding of CIMs, obtain design inspiration and stimulate creative design activity, this paper reports on the development of a framework for a taxonomy of CIMs. Through literature review and analysis of existing design tools, the purpose, ending conditions, basic methods and framework of a taxonomy were identified. Taking Xuan Paper as an example, a case study was undertaken to establish methods and processes. When combined with expert interviews and user questionnaires, the usefulness, efficiency and acceptability of the research framework were evaluated, optimized and validated. The findings indicate that a CIM taxonomy can support designers to systematically acquire materials and processing information, facilitate materials-driven creative design, material comparison/selection and provide a framework for the construction of CIM-related databases.

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Introduction

In the context of an increasingly competitive commercial environment for industrial design, interest is emerging in the exploration of material qualities to enhance product experience (Veelaert et al., 2020). Materials have two overlapping roles—to provide technical functionality and to create product personality (Ashby and Johnson, 2014). To meet the needs and desires of end users, industrial designers must select materials that thoughtfully balance functional and expressive product requirements (Pedgley, 2013). As such, designers must continuously acquire knowledge related in material properties with a particular interest in colour, material and finish (CMF).

Chinese indigenous materials (CIMs) and crafts represent a resource that has been largely ignored by designers. CIMs incorporate qualities that are inherent, unique and traditional as a resource of contemporary raw materials or processed materials. This leads to potential benefits for trans-sector collaboration between traditional crafts and digital/material technologies (Zhan et al., 2017). By using traditional and indigenous materials that reflect regional and/or historical characteristics, crafts resulting in non-repeatable features and aesthetics can be employed by designers to give products an emotional connection with specific cultural contexts and stimulate emotional attachment (Camere and Karana, 2018; Karana et al., 2018; Rognoli, 2015). CIMs and relevant crafts are important sources of creativity, providing materials and innovative inspiration for contemporary design (Duan, 2013; Duan et al., 2019; Feng, 2009; Feng and Wang, 2021).

CIMs have typically been considered as raw materials or craft-related products. It is generally accepted that craft and craftsmanship are consistent with the principles of sustainability (Zhan et al., 2017). Crafts and manufacturing processes for CIMs are identified as Intangible Cultural Heritage (ICH), some of which are in decline and on the verge of being lost. This means that the inheritance and interpretation of CIMs are closely connected with the longevity of ICH. In the context of modernization, innovation based on CIMs can be an effective approach for the longevity and dissemination of ICH. The flexible, localized, customized nature craft-driven manufacturing is consistent with this emergent direction and anticipated trend (Prendeville et al., 2016).

In exploring the Han Dynasty, Wang Ji's comments that "Different regions have different customs." The variation of geographical locations, climates, environment and traditions result in different customs and cultures. Utilizing materials with regional characteristics has the potential to enhance the aesthetic of product materials but also highlight regional characteristics and endearment, giving materials unique value, emotional appeal and poetic expression (Lyu et al., 2018; Zhu, 2019) In addition, the relationship of CIMs with regional cultures deliver a unique experience to users (Wei et al., 2019) enabling diversified designs and emotional responses.

Having identified opportunities for CIMs in contemporary industrial design, there is a need for a systematic collection, identification and classification of CIMs. A creative design-oriented framework of a taxonomy for CIMs and relevant crafts is proposed as a tool and knowledge framework to support designers in acquiring useful knowledge. As such, the objectives of this study were to identify CIMs and relevant crafts; develop a classification system of key material properties of materials and crafts; translate the knowledge framework into a tool-based format suitable for use by industrial designers; produce pilot case studies to demonstrate the contemporary potential of this taxonomy; undertake the initial refinement of the tool based on pilot study findings; evaluate the tool with industrial designers (novice/practitioners); undertake final refinement of the tool; and provide recommendations for complete system. The authors developed the taxonomy structure and used "Xuan Paper" in a case study to present the taxonomy structure and acquire user feedback.

The research design employs a systematic review of current tools for design materials, taxonomic classifications, CIMs/relevant crafts, and existing design material classification methods. Using Xuan Paper as an example, the construction of the basic taxonomy structure is identified and, through expert interviews and questionnaires, its usefulness, efficiency and feasibility are investigated and refined to optimize the taxonomic framework.

Related researches

Material information needed for design inspiration and material selection

Material inspiration. The term "inspiration" refers to the ability to stimulate creative thinking in which innovative products can be generated through the use of materials and processes (Ashby and Johnson, 2014). Materials inspiration implies material-driven creativity that occurs synchronously with design ideation and which, to some extent, permits a material to 'lead the way' with regard to form—giving and possible user experiences (Pedgley et al., 2015).

Inspiration can be triggered by direct interaction with materials on existing products via material samples and images (Ashby and Johnson, 2014). Web-based databases and material libraries also offer a comprehensive resource for design inspiration.

Material selection. Karana et al. (2010) define the term "material selection" as the selection of appropriate materials for designed products by considering related design criteria, such as manufacturing processes, availability, cost, function, shape, use, as well as meanings, associations, emotions, characteristics of users and cultural aspects.

Material selection begins with the initial screening of all possible materials through comparing and ranking alternative materials to select optimum solutions. The appropriate selection of a material is critical to the success of a product (Hodgson and Harper, 2004). According to Haug (2019), material knowledge can be both tacit and explicit, acquired by using the categories of know-what, know-who, know-why, and know-how. Through interviews with industrial designers, van Kesteren (2008) found four needs of materials in material selection—for comparable information, information related to product issues, information on multiple detail levels and material samples. Kesteren also identified three types of information required by designers—general material applications (experience, testing, example products); independent sources (databases, search engines; sample collections; books, exhibitions which were used to build experience); materials supply (suppliers, Internet online databases, samples, brochures; trade shows, and magazines) (van Kesteren et al., 2008). Ashby and Johnson (2014) identified the three methods of material selection for industrial design—analysis (deductive reasoning), synthesis (inductive reasoning) and similarity, inspiration; Ashby and Johnson (2014) also suggested that the best solution was to combine all of these.

Current design material tools and research. The most widely used material selection methods are based on performance indices and material property charts (Ashby and Johnson, 2014) such as computer software tools (CES), databases (Matweb) and physical material libraries (Material Connexion) (Prendeville et al., 2014) However, products are differentiated not only by their technical functions but also the way in which materials are perceived by the user (Karana and Hekkert, 2008). Unlike technical design requirements which are defined in quantitative terms

that can be objectively assessed, industrial design characteristics are expressed in qualitative terms that are more subjective and difficult to qualify (Ludden et al., 2008).

Simultaneous consideration of both technical and industrial design aspects when selecting materials is important but represents a significant challenge (Karana et al., 2013). As such, research interest has started to shift from technical to user-centered to explore the meaning of materials, material experience, material seniority and material-driven design (Ashby and Johnson, 2014; Fallman, 2008; Karana and Hekkert, 2008; Karana et al., 2009, 2010, 2018; Lefteri, 2014; Pedgley et al., 2015; Rognoli, 2015; van Kesteren et al., 2007). Corresponding tools, such as material selection, material information acquisition and material inspirations for design have been developed. These include 'The Material Explorer' database the expressive-sensory dimension of materials (Rognoli and Levi, 2004), 'Meanings of Materials' (MoM) tool (Karana et al., 2010), and 'Materials in Products Selection' (MiPS) tools (van Kesteren et al., 2007). However, these employ products made of contemporary materials and focus on specific manufacturing processes or user interactions meaning that the results or experiences are not applicable to CIMs. Furthermore, as a new research field, material-driven design (MDR) uses materials as a driver of a creative "finding" process by evoking and consolidating ideas and takes materials as creative opportunities for idea generation (Karana et al., 2013; Yin et al., 2017). Basing on MDR, this study develops a framework of CIMs to motivate and guide designers in creative product development.

Taxonomy. A taxonomy is a form of classification that plays an important role in research and management because the classification of objects supports researchers and practitioners in their understanding and analysis of complex domains (Nickerson et al., 2013).

Taxonomy, taxology and classification are organizational techniques that can overlap and be used interchangeably (Bailey, 1994; Nickerson et al., 2013; Rich, 1992). Nickerson et al. (2013) identify "A method for taxonomy development and its application in information systems" and clarify the terms "classification", "framework", "typology" and "taxonomy". Classification is used to refer to both the system or process of organizing objects of interest and the organization of the objects. Framework is used for organizing objects and its definition closest to the classification system. Typology is restricted to a system of conceptually derived groupings. Taxonomy is perhaps the most confused term, being used for the system or process and the result of applying the system. Baily (1994) argues that typology and taxonomy are both classification techniques, with special emphasis on cluster analysis and consideration within knowledge organization. Nickerson et al. (2013) comments that taxonomy is the most common term. This study uses the term "taxonomy" to refer to our relative classification groups.

Published taxonomies range from simple to complex. Nickerson et al. (2013) classified the approaches used for developing a taxonomy into three categories: inductive, deductive and intuitive. The inductive approach involves observing empirical cases to determine dimensions and characters in the taxonomy while the deductive approach identifies dimensions and characters by a logical process derived from a found conceptual or theoretical foundation. The intuitive approach has no explicit method and is essentially ad hoc with researchers using perception and understanding to propose a taxonomy. There is a significant amount of literature about the classification of design materials (Ashby and Johnson, 2014; Beylerian et al., 2007; Howes and Laughlin, 2012; Lefteri, 2004, 2014; Zhan et al., 2017), but few identify the classification of CIMs or provide empirical cases. This study combines inductive and deductive approaches.

Baladi points to the basic principles of taxonomy that include perceptual orthogonality, completeness and parallel structure (Baladi et al., 2007). Nickerson et al. (2013) also propose that a useful taxonomy should be concise, robust, comprehensive, extendable and explanatory. However, as noted by Baladi et al. (2007), these principles are the goals of a taxonomy and there is no one correct way to approach this. As this study aims to propose a taxonomy framework for CIMs, we take the identified principles as our goals, collect data as comprehensively as possible, design its perceptual orthogonality/parallel structure and strive to make the framework meet the quality requirements put forward by Nickerson et al. (2013).

CIMs and relevant crafts. Research on art/graphics of CIMs and relevant crafts has explored production skills for materials, artistic characteristics and shape evolution of handicrafts and artworks (Duan et al., 2014; Lou, 2011; Tian, 2014). When identifying CIMs as a cultural phenomenon, research has explored the cultural connotation, diachronic development, cause of formation and cultural field of CIMs from the perspective of anthropology and ethnology (Jia and Jia, 2015; Ma, 2021). Taking CIMs as a form of cultural heritage, research findings have identified the cultural protection of artistic wealth and creative design research, with classification according to their attributes (Lu, 2017; Ni, 2021; Wang, 2006; Zhan et al., 2017).

In exploring the cultural values of CIMs, Duan and Xuan (2021) identify a considerable amount of research on the development path and strategy of Chinese ICH, creative design methods of derivatives, the value of creative industries, modern expression, inheritance of cultural connotation and the transformation of artistic form through in-depth excavation of cultural connotation (Duan and Xuan, 2021). The creative drive of regional materials has been recognized by a significant number of scholars (Feng, 2009; Jia and Jia, 2015; Lu, 2017; Lyu et al., 2018; Ma, 2021; Wei et al., 2019).

Design materials taxonomy. Design materials generally have a classification of materials that form a structural framework. There are a number of approaches to materials classification—material families (Ashby and Johnson, 2014; Howes and Laughlin, 2012; Lefteri, 2004); composition (Beylerian et al., 2007; Lefteri, 2014); and a combination of material families and composition (Akın and Pedgley, 2016; Beylerian and Dent, 2005). For example, Lefteri (2004, 2014) defines a design materials framework through introductions, images of products, explanation, key features, sources, sustainability, production, advantages/disadvantages, typical applications, sources, cost and additional online information. According to existing classifications, these tend to have images of materials or typical products manufactured using them along with accompanying explanations. Some texts/papers have an introduction of the whole classification—about ('what it is?'), properties and application fields ('how they were used in production or manufacture'/production process) (Beylerian et al., 2007). Others have design notes (design notification) and technical notes(Ashby and Johnson, 2014). In this study, the taxonomy applies these studies in the generation of the taxonomy hierarchy and organizing information on materials.

Methodology

Research design. Wemmerlöv (1990) addressed the foundation for taxonomy as its purpose, organizational level of analysis, categorizing variables and operationalizing variables. Bailey (1994) proposed a three-level indicator model to provide a basis for developing taxonomies that involve approaches of deduction and induction. Furthermore, Nickerson et al. (2013) proposed a

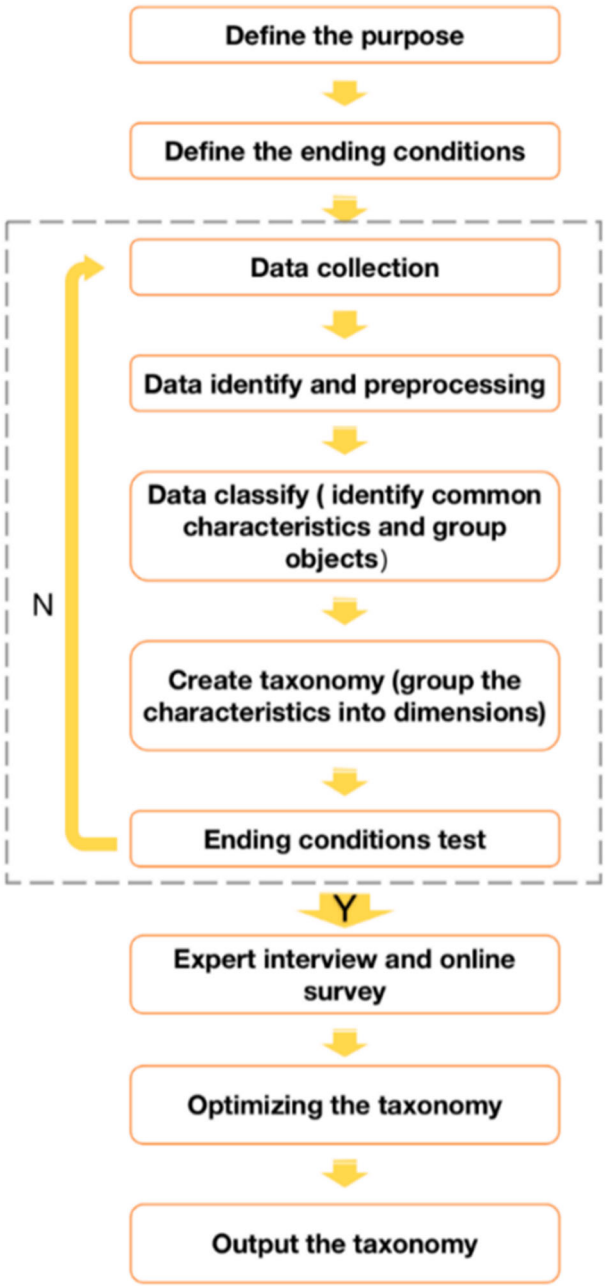


Fig. 1 The research flow of the proposed taxonomy framework. Alt Text: The research flow started from define the purpose, leading to define the ending conditions, leading to a cycle that included data collection, data identify and preprocessing, data classifying, create taxonomy, ending conditions test; If the test result is No, leading back to data collection; If the test result is Yes, leading to expert interview and online survey, leading to optimizing the taxonomy, and then leading to output the taxonomy.

taxonomy development method by adding the concept of meta-characteristic and specific ending conditions. Based on the above methods, the research design for this study is presented in Fig. 1.

Define the purpose of the taxonomy. The purpose of a taxonomy should be based on expected use and defined by its eventual users. (Nickerson et al., 2013) The users in this study are industrial designers who will employ the taxonomy as a decision-making tool for design-related problems and to be inspired by CIMs during concept design activity and material selection. Its purpose is to effectively and unambiguously organize the design information of CIMs in a clear hierarchical structure to enable designers to acquire comprehensive design information related to CIMs and facilitate understanding of material opportunities, inspiration and selection. As such, the meta-characteristics of the taxonomy are defined as a design material selection tool, source of inspiration and CIMs design resource.

Define the end conditions of the taxonomy. Baladi et al. (2007) identify the basic principles of taxonomy as perceptual orthogonality, completeness and parallel structure. Perceptual orthogonality preserves the uniqueness of every classification or taxon and every category. Completeness requires that taxonomy should include all known aspects of the field within the domain being classified. Parallel structure considers the hierarchical nature of taxonomy and finds abstractness for taxons of the same rank (Baladi et al., 2007). Nickerson et al. (2013) also propose that a useful taxonomy should be concise, robust, comprehensive, extendable and explanatory (Nickerson et al., 2013). However, as Baladi et al. (2007) have identified, the principles are just goals for a taxonomy and there is no one correct way to approach theses.

As the aim of this study was to propose a taxonomy framework for CIMs and relevant crafts, the related principles proposed by Baladi et al. (2007) and Nickerson et al. (2013) were applied by collecting relevant information, designing perceptual orthogonality/ parallel structure and making the framework meet the quality requirements put forward by Nickerson et al. (2013). However, in the context of the objectives for the study, it is more important to propose the framework than provide completeness of information. Therefore, we determined the following end conditions for the study:

Objective end conditions: no new dimensions added in the upper level; no additional kinds of information provided.

Subjective end conditions: presentative (typical) users/experts agree that the taxonomy framework has perceptual orthogonality, is comprehensive, concise, explanatory and has a parallel structure.

Data collection. Data collection employed a survey of relevant literature sources on CIMs and relevant crafts using national and local provincial ICH websites, interviews with inheritors of ICH and senior designers who had engaged in the design of creative products based on Chinese traditional culture.

As the aim of the research was to study the taxonomy framework of CIMs and relevant crafts, the main task was to collect and classify relevant information as fully and widely as possible to build a framework based on existing resources as opposed to identifying every material. As such, its focus was on the material itself rather than the design-oriented material taxonomy. In this process, the image, text, video and sample resources of more than 30 kinds of material identified as CIMs were collected.

Data identification and pre-processing. After the collection of material data, artefacts need to be identified as Chinese indigenous or unique materials, tools or crafts. Three industrial designers with more than 5 years of design practice experience and two researchers engaged in research on CIMs and crafts-related culture were recruited to form an expert group. They were invited to achieve a consensus of opinion in identifying the representativeness and design value of materials based on cultural experience and outcome. This included identifying the uniqueness or origin of the material, cultural value, its relevant crafts (design-driven value), and value in terms of contribution to industrial design. For example, Chinese traditional paper

materials include hemp paper, leather paper and bamboo paper. Amongst these, hemp paper was one of the earliest types, with a matte surface, abundant fibre bundles, easy ink absorption, strength and longevity. However, according to the analysis of the expert group, although it has excellent material properties and a long cultural history, the paper has not been in use since the Ming and Qing Dynasties. There was no use in contemporary manufactured products so it was difficult to identify its usefulness in design innovation. Hemp paper was therefore considered as being of limited design value and was not used in the early identification process.

The feasibility of the design and development value of collected materials and their relevance with Chinese regional characteristics and culture were acquired through expert interviews. In addition, materials were selected that met the screening criteria for further research under the guidance of experts. Material selection criteria were determined for constructing the material library and screening of collected materials. After screening by experts, 20 representative materials were selected.

Data classification. After determining the representative materials, an additional phase of data collection was conducted by referring to material classification and material information requirements related to design in the literature review.

Lundvall and Johnson (1994) identified four types of knowledge—know-what, know-who, know-how, and know-why. The know-what of materials includes information about the material colours, transparency, durability, density, and texture. The know-who of materials includes information about who can supply the material which is the basis for knowing the price, delivery times, reliability of delivery. The know-how of materials includes an understanding of how to process materials (Haug, 2019). Properties of materials can be categorized into two groups—technical aspects and the user-interaction aspects (van Kesteren, 2008). Information that combines technical and aesthetic aspects of materials can reduce the number of iterations during material selection (van Kesteren et al., 2008).

In this stage, we were committed to collecting engineering information and design information. Engineering information related to production processes, cost, physical and chemical properties. Design information consisted of the historical heritage of materials, the emotional perception of users, and creative design cases based on the materials.

For the needs of designers, they were sorted into original materials and creative case studies. According to the types of data, were divided into image data, audio data, visual data and physical sample data. For the category of information, the data of each individual material was divided into materials, process and design. According to the corresponding classification, an information document was set up for each material and the corresponding materials/links collated to facilitate post-processing.

Taxonomy structure construction

Defining level of analysis. Levels of analysis can vary depending on the purpose (Céret et al., 2013). For this study, the taxon levels include the basic CIMs taxon, relevant crafts taxon and creative design-related information taxon. Effective and unambiguous taxonomies can only be formulated at a low level of aggregation (Wemmerlöv, 1990). So it is necessary for the taxonomy to contain as few and centralized levels as possible.

In the classification of basic CIMs, Lefteri's (2014) approach was employed and based on raw materials i.e. Grown, Mined and Others for Level 1 of the taxonomy framework. Levels 2 and 3 were also classified based on this method. When coming to a material that was difficult to classify, we focused on the classification of relevant properties, processes, design applications and other information and moved on to the lower level.

End conditions test. The end conditions are identified by referring to the work of Nickerson et al. (2013), Leferti (2004, 2014) and combining previous interviews with the designers as follows:

I. The taxonomy is comprehensive, robust and reliable.
II. All the information identified relating to CIMs had been allocated to the existing levels.
III. The same level contained minimal overlapping information and the upper and lower levels had firm and reliable inclusive relationships, extensible relationships and explanatory relationships i.e. the upper level included the lower information and the lower information was the extension and interpretation of the upper level.
IV. The taxonomy met the objective conditions of perceptual orthogonality, completeness, parallel structure and subjective conditions of being concise, robust, comprehensive, extendable and explanatory (Nickerson et al., 2013).

The end condition test was performed after each level of a specific CIM was established to ensure that the taxonomy had a simplified and comprehensive framework.

Case study

Paper is one of the four great inventions in ancient China. Xuan Paper is the essential medium for Chinese calligraphy, painting and other arts, with a long history and unique cultural relevance. It has good physical and chemical properties and is widely used in various handicraft materials. In our material research and collection, it was identified by experts to be a highly representative CIM. Therefore, a basic taxonomy framework for CIMs and relevant crafts data classification was constructed taking Xuan Paper as an example.

Construction of the basic taxonomy framework

Level 1. With reference to the Lefteri classification method of materials for design, CIMs for creative design were classified into three taxons: Grown, Mined, Others.

Level 2. Three taxons of Level 1 were classified with reference to the classification methods of Leftri (2004, 2014) and Howes (Howes and Laughlin, 2012). As shown in Table 1, Grown is

Table 1 Structure of levels 1-3.

	Level 1	Level 2	Level 3
Chinese indigenous materials	Grown	Plant	Bamboo
			Grass
			Wood
			...
			More
		Animal	Silk
			Leather
			Shadow Play
			Ponytail
			...
			More
	Mined	Fibre	
		Ceramic	
		Stone	
		Metal	
		More	
	Others		

Table 2 Structure of Levels 4–6.

Level 3	Level 4	Level 5	Level 6
Wood	Paper	Xuan Paper	Introductions Material Properties Relevant Typical Traditional Arts & Crafts Manufacturing Process More Information
		Oil Paper Gauze Cotton Paper Hemp Paper Bamboo Paper More	
	Lacquer Woodworking Tools Puppet Horse Spoon ... More		

classified into Plant, Animal, Fibre; Mined is classified into Ceramic, Stone, Metal and More.

Level 3. Based on the classification of Level 1 and Level 2 plus related principles of taxonomy (orthogonality, completeness, parallelism), data collected from literature, websites and other resources (markets, museums, ICH experts) were classified. As our research focused on the classification of CIMs for fostering creative design, in order not to miss information on materials that may be valuable for creativity, our materials include some that were less common or unfamiliar to designers. The structure of Level 3 is built on details classified in Level 2, such as the classification of Plants and Animals as shown in Table 1.

Level 4–Level 8. Level 4 represents a further classification of Level 3 with the following characteristics:

I. Some materials may be processed materials or products but these can still be used for supporting the design of products by providing material, symbol and inspiration.
II. Due to secondary processing, some materials may not only be made from a single material of the upper level (e.g., paper made of bark, grass and other materials). But, as trees and bark were the main raw materials that determine the variety and characteristics of paper, it was classified as wood. Therefore, according to the principle of orthogonality, the paper would not be classified into any other category.

According to these principles, wood was taken as an example of Level 4. Similarly, the paper was taken as an example of Level 5 and classified as shown in Table 2.

Based on published work, (Howes and Laughlin, 2012; Karana et al., 2009; Lefteri, 2004, 2014; Pedgley et al., 2015; Rognoli and Levi, 2004), Levels 6–8 were classified as shown in Table 3. These levels include the description, analysis and explanation of relevant properties, their application in art/crafts, and manufacturing processes.

Level 9 includes details of Level 8, especially the details of "Relevant Typical Traditional Arts & Crafts" as shown in Table 4.

Pilot survey. After defining the basic taxonomy framework for CIMs and relevant crafts, a pilot survey employing one designer and two design educators with more than 10 years of experience in cultural and creative product design was conducted to further improve and verify effectiveness. All of the participants majored in industrial design and two were design educators with more than 10 years' experience. One had a Chinese master qualification and was studying in the UK for a second master degree.

The purpose and methods of the research were explained and framework introduced. Interviewees were asked questions shown in Table 5.

Findings indicated that materials were selected by personal knowledge (3/3), existing company suppliers (2/3), material sample libraries (2/3), materials already used (1/3) and recommendation from experts (1/3). They believed that CIMs and relative craft stimulated them during the design of cultural designs (3/3) by providing design opportunities, inspiration and information on traditional crafts. After reviewing the framework, they agreed that it was logical and useful (3/3) and would be happy to recommend it to colleges/students (3/3). They also listed reasons as to why it was most useful in the framework, these being material/technical properties (2/3), eco properties (2/3), and the relationship between the material and the craft or art (2/3). To improve the framework, they pointed that it should be made interactive by linking to the corresponding information, level or website. They recommend that it should have more material information and design case studies.

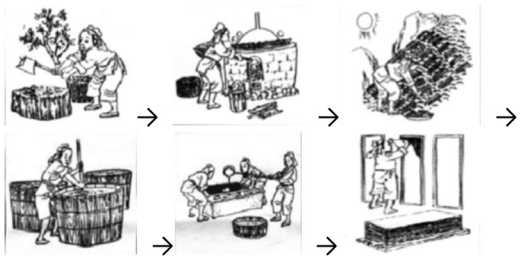
The framework was followed by iterative refinement through expert interviews. To make this interactive, clicking on the picture in the case study displayed the corresponding high-resolution picture and clicking on the "More" taxon in the framework linked to the corresponding webpage and literature website for relevant materials/crafts. Additional material information and design case studies were also added e.g. contemporary creative design case studies such as lamps, furniture and architectural features inspired by paper folding and paper cuttings processes.

Online survey and data analysis. Asking users to evaluate the usefulness of the taxonomy represents one way in which to evaluate the taxonomy. It was necessary to validate usefulness and effectiveness of the taxonomy by users (Nickerson et al., 2013) and this included essential features of usability influence on creativity (Van Kesteren et al., 2007). This was achieved through the use of a questionnaire.

The questions focused on sources of information selected by users i.e. existing materials, creative inspiration, usefulness, acceptance of the taxonomic framework and suggestions for further optimization (shown in Table 6). After revising the classification framework, this was displayed on an online website in the form of interactive PDF files that were distributed to designers and educators engaged in industrial design and product design in China plus graduate and undergraduate students studying in China, the United Kingdom, Republic of Korea and the United States. To ensure the effectiveness of participant evaluations for the study, they were required to be Chinese citizens with an educational background or work experience in industrial/product design (including those studying or working abroad) and familiarity with Chinese culture. Meanwhile, all participants must be over 18 years old.

A total of 235 valid questionnaires were received, comprising 100 males, 135 females, 177 practitioners or students of industrial design and 58 practitioners or students of product design. The online survey results are shown in the Appendix.

Table 3 Structure of Level 6–Level 8 of Xuan Paper.

Level 6	Level 7	Level 8
Introductions	What it is	One of the Four Treasures of Study, Xuan Paper has been the carrier of Chinese unique calligraphy and painting. It enables Chinese calligraphy and painting to be circulated and preserved i.e., Xuan Paper is often referred to as "Millennium Life Paper" and the "King of Paper".
	Typical product applications	 Notebook; Lampshade; 2018 Olympic prize certificate (*Alt Text*: Four pictures are shown here, the first is a stack of notebooks; the second is a lampshade; the third is the 2018 Olympic prize certificate; the fourth is the package of Qianmu Xuan Paper.)
Material properties	General property	Price, good density, handmade (mostly)
	Technical property	Durability, good wettability, stability, insect resistance
	Eco property	Easy to form, no dyeing, low carbon, recyclable
	Aesthetic property	Tough, smooth, white, dense, pure texture, nondestructive when rubbing, strong ink moistening property Sight: white, dense, smooth, matte, opaque or translucent Touch: warm, soft, light, sliding, dry Smell: neutral, nature paper smell
Relevant typical traditional arts & crafts	Painting	General Introduction Relationship with Xuan Paper Traditional Applications Innovative Applications More Information
	Calligraphy	Same as "Painting"
	Cutting	Same as "Painting"
	Folding	Same as "Painting"
	Sticking	Same as "Painting"
Manufacturing process	Raw Materials	Sandalwood branch, rice straw, charcoal, alkali and bleaching powder, etc.
	Process	Raw material selection→ Crush the main ingredients→ steam heating→ Dry naturally→ Dried bark and other raw materials further crushed, soaked, fermented, beaten, and added to tree paste to form pulp→ Pulp hand-made into Xuan Paper using a paper machine→ Paper placed in the sun to dry
	Manufacturing process diagrams	 (*Alt Text*: the process diagrams of Xuan Paper, and the steps are as described in "Process")
	More information	http://www.360doc.com/content/22/0406/23/11709357_1025181186.shtml, etc.
More information		Search key words: Xuan Paper, Rice Paper, Chinese Xuan Paper, Chinese Traditional Paper, Xuan Paper Artwork, Jingxian Xuan Paper, Story of Xuan Paper, Xuan Paper Making Process, Xuan Paper in Modern Design, etc.

Results from the questionnaires indicated that users relied more on personal knowledge, material databases or previous material experience in material selection and had less experience in using a materials sample library. The main limiting factors for designers when selecting materials were—existing suppliers (46/68), company policy (37/68), design inspiration by browsing a website (141/235), Pinterest (105/235), Baidu Gallery (96/235), Behance (91/235) and Weibo (65/235). They also mentioned a WeChat public account, E-commerce platform and access to natural resources.

A Likert scale from −3 to 3 was used to identify attitudes, with −3 being completely disagree, −2 disagree, −1 slightly disagree, 0 neutral, 1 basically agree, 2 agree, and 3 fully agree. After reviewing the PDF describing the framework, 217/235 of the participants would consider using the proposed taxonomy during their creative process. When asked why, "To acquire traditional crafts or product information knowledge" received the highest score (2), followed by "To find design and/or material opportunities" (1.93)", "To review successful case studies" (1.81), "To find a material information resource/library" (1.81)

Table 4 Part of the structure of Level 6–Level 9.

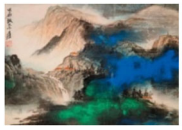
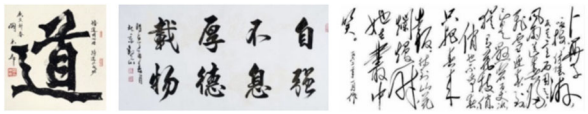
Level 6	Level 7	Level 8	Level 9
Relevant typical traditional arts & crafts	Painting	General introduction	Originated in Han Dynasty and form of traditional Chinese painting. Applied to crepe or Xuan Paper with brushes, water, ink and colour. Content and artistic creation of Chinese painting reflects ancient understanding of nature, society, politics, philosophy, religion, morality, literature and art.
		Relationship with Xuan Paper	Xuan Paper is pure and delicate and suitable for Chinese painting. Xuan Paper helps the painting last.
		Traditional applications	 ... (*Alt Text*: There are 3 pictures. The first is a landscape Chinese painting; the second is a Chinese horse painting; the third is a Chinese painting of people named "Eight Immortals Crossing the Sea".
		Innovative applications	 ... (*Alt Text*: There are 4 innovative Chinese painting pictures. The first is an abstract freehand lotus flower; the second is an ink painting of a human and a horse with a sharpened style; a third picture is a group of three pictures, all of which are different manifestations of thick ink marks that have strong visual tension and are similar to circles; the fourth is the package of a kind of Chinese black tea.)
		More information	https://baike.baidu.com/item/%E5%9B%BD%E7%94%BB/5323?fr=aladdin, etc. Search Key words: Chinese Traditional Painting, Chinese Painting, Chinese Ink Painting, Chinese Ink Painting Design, Traditional Chinese Ink Painting Inspired Design, Ink Painting Style Product Design, Oriental Aesthetic Product Design, Ink Strokes Style Product Design, East Meets West Design with Chinese Painting, etc.
	Calligraphy	General introduction	Chinese calligraphy is the writing art of Chinese characters. It is a symbol of China and Chinese traditional culture and is the most representative national art. It uses Chinese characters as the carrier and lines as the means. Through straight lines and varying weights, the characters are shaped to reflect the book's aesthetic.
		Relationship with Xuan Paper	Xuan Paper is suitable for Chinese calligraphy of brush and ink. Its hydrophilicity enables calligraphers to write freely without restriction
		Traditional applications	 ... (*Alt Text*: These pictures are traditional Chinese calligraphy works. The first is a character "Dao" written in the running script font; the second is a famous quote written in the running script font; the third is a Chinese poem written in the cursive script font.)
		Innovative applications	 ... (*Alt Text*: The first picture is a modern poster design with calligraphy art as its theme; the second is the package design of coarse cereals; the third picture is a screen decorated with a pattern using calligraphy font as the design element; the fourth is a kind of painting paper).
		More information	https://baike.baidu.com/item/%E4%B8%AD%E5%9B%BD%E4%B9%A6%E6%B3%95/678#viewPageContent, etc. Search Key words: Calligraphy, Chinese Calligraphy, Calligraphy Product Design, Creative Calligraphic Innovations, Calligraphy-Inspired Design, Ink and Paper Product Design, Brush Strokes in Design, etc.
	Cutting	General introduction	Chinese paper-cut is a form of folk art that uses scissors or knives to cut and carve patterns on paper for decoration or cooperation with other folk activities. In China, paper-cut has a broad mass base, blending in the social life of people of all ethnic groups, and is an important part of folk traditions. Its continuous visual image and modelling format contain rich cultural and historical information and expresses social cognition, moral concept, practical experience, life ideals and aesthetic interest.
		Relationship with Xuan Paper	Xuan Paper is suitable for cutting paper art for its softness and wettability. It can be used for spot dye paper cutting.
		Traditional applications	 ... (*Alt Text*: These three pictures are paper-cutting works of art. The first is a monochrome paper-cutting of a figure; the second is a monochrome paper-cutting with a landscape theme; the third is a coloured paper-cutting of a figure.)

Table 4 (continued)

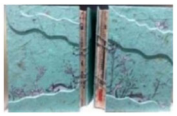
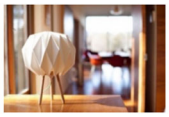
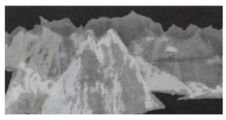
Level 6	Level 7	Level 8	Level 9
		Innovative applications	    ... (*Alt Text*: These three pictures are innovative applications of paper-cutting art. The first is a bookmark that incorporates paper-cutting elements; the second is a female portrait made using paper-cutting techniques; the third is an illustration made using both paper-cutting and collage techniques which depicts a little boy sitting on an airplane as if he were riding a horse; the fourth one is the package of tea.)
		More information	https://baijiahao.baidu.com/s?id=1610204241517368960&wfr=spider&for=pc, etc. Search Key words: Paper cutting, Cutting Paper, Jianzhi, Papercutting Product Design, Paper Cutting Design, Cutout Product Innovations, Papercutting Inspired Design, etc.
	Folding	General introduction	Paper folding originated in China and has been widely developed in Japan. Paper folding is rich in form, complex in structure and lifelike. It is a creative activity that is both challenging and enlightening. By integrate the principle of modern three-dimensional composition into paper folding and developing multiple complex combination forms, artists study the paper space from a deep level, apply it to modern poster, packaging and product design, and bring more shocking visual enjoyment to the audience.
		Relationship with Xuan Paper	Xuan Paper is soft and durable, which make it easy to be folded, stacked and moulded. The folding of Xuan Paper can be moulded, stacked, curled and laminated. After folding, it can be used to make a variety of traditional or modern products, such as paper fans, furniture and books.
		Traditional applications	   ... (*Alt Text*: The first picture is a lamp, with the shape of a book opening the page; The second picture shows a foldable lantern-shaped lamp; The third picture is an open folding fan shaped artistic installation.)
		Innovative applications	    ... (*Alt Text*: The first picture is a paper folding sofa chair that can be extended and folded; the second picture is a single-person sofa made by stacking Xuan paper; the third picture is a bookbinding design using paper's texture and embossment; the fourth one is a light with the shape of folding paper.)
		More information	http://www.zhidiy.com, etc. Search Key words: Paper Folding Design, Origami Product Design, Foldable Product Innovations, Origami Inspired Design, Foldable Materials in Product Design, Paper Crafted Products, Folding Techniques in Design,etc.
	Sticking	General introduction	The sticking of paper is not a specific art or craft in China. It is post-processing performed after folding, cutting, rubbing and other operations. Xuan Paper is bonded to form a new product or pasted to form a three-dimensional picture or used in the production of three-dimensional books.
		Relationship with Xuan Paper	Xuan Paper is soft, flexible and hydrophilic and easily crushed, reshaped and bonded without being damaged. Due to its good hydrophilicity, it can be bonded with traditional Chinese adhesives (mainly viscous pastes made from cereals) and is structurally stable, firm and permanent after gluing.
		Traditional applications	   ... (*Alt Text*: The first picture is a lamp in the shape of an "Kongming" light; The second picture is a traditional lighting fixture composed of Xuan Paper and Chinese traditional painting elements; The third picture is a paper rabbit made by collage and pasting.)
		Innovative applications	    ... (*Alt Text*: The first picture is a luminaire crafted from sticking paper; the second picture is a creative notebook incorporating sticking paper materials; the third picture is a landscape painting created by pasting torn Xuan paper after crumpling; the fourth is a paper sculpture.)
		More information	https://www.zhidiy.com/zhiyixinshang/1997/, etc. Search Key words: Sticking Paper, Sticking Paper Product Design, Paper Adhesive Design, Adhesive Material Innovations in Design, Sticking Paper-Inspired Design, Adhesive Materials in Product Design, etc.

Table 5 Questions for designers' interview.

No.	Questions
1	How do you currently select materials?
2	Will the CIMs and relevant crafts facilitate your creativity when doing cultural and creative design? What is the specific performance?
3	Do you think the taxonomy useful for designers? List 1–3 reasons as to why you think it is most useful for designers.
4	Would you recommend it to your colleagues/classmates/students?
5	How could the taxonomy be improved?

Table 6 Questions of the questionnaire.

Information	Questions
Basic information	Gender
	Area of expertise
	Occupations
Material selection	How do you currently material select?
	If you are a design practitioner, are there limitations on your material selection choices?
	If you are a design practitioner, what is your priority of importance of material to you when designing?
Material inspiration	When designing, where do you currently look for design inspiration?
Usefulness	Having reviewed the attached PDF describing the framework, would you consider using a Chinese indigenous material taxonomy during your creative process?
	Why yes?
	Why other?
	Why not? Could you please specify?
	Do you feel it would be a useful resource during your design activity?
Acceptance	Have you considered using Chinese indigenous materials before?
	Would this framework of CIMs taxonomy make you more likely to use Chinese indigenous materials?
	Have you use a taxonomy before?
	Would you recommend it to your colleagues or classmates/students?
Clarity and logic	Do you think the taxonomy present itself clearly?
	To make it clearer, you would prefer to recommend us to:
	Do you think it has a logical structure?
	Why do you think its classification structure is not reasonable?
Refinement	Do you think the taxonomy is useful for designers?
	Why do you think it is useless, please specify:
	Please list 1–3 options you think is most useful for designers:
	Please list 1–3 options you think are least useful for designers:
	How could the tool be improved?

and "To find creative inspirations for your design" (1.72) (see Fig. 2). Reasons for selecting "other" included "It can match the design inspiration and materials in the mind faster", "The logic is strong and the thought flow could be expanded", "The integration of information resources is helpful to develop design thinking", and "It help spread Chinese culture and reflect national connotation". Only 16/235 participants thought the framework was not suitable with reasons given as "Not convenient practical" (5/16), "Does not meet industry characteristics" (3/16) and "failing to effectively stimulate the breakthrough creativity in overall design" (2/16). Most of the participants (230/235) felt the taxonomy would be a useful resource during design activity and 213/253 believed the taxonomy made them more likely to use CIMs with only 156/235 having considered using CIMs before (Fig. 3). When asked if they would recommend the taxonomy to colleagues or classmates, 205/235 were positive and 23 were neutral (Fig. 4).

When asked about the clarity of the taxonomy, 27 were neutral, 144 agreed slightly, 54 totally agreed and disagreed slightly (Fig. 4). Most of the participants agreed that the taxonomy was clearly presented. Participants who ticked the negative or zero scores were invited to recommend improvements with responses including "Add more case studies" (18/24), "Add complementary text & figures" (17/24) and "Add more information & levels" (17/24) (Fig. 5). When asked if the taxonomy had a logical structure, 214/235 participants had a positive response and 20/235 were neutral with 1/235 disagreeing slightly (Fig. 4).

In terms of the usefulness of the taxonomy for designers, 213/235 participants gave a positive response, 20/235 neutral, 1/235 slightly disagree and 1/235 disagree (Fig. 4). Three participants gave reasons as to why it was not useful: "Lack of design practice", "It is just a simple classification and need in-depth analysis of its characteristics" and "It does not show the correlation and connection between different materials". When asked to list 1–3 options they thought were the most useful and least useful, the most significant responses were "Material properties: general property" (91/235), "Introduction: typical product applications" (90/235), "Relevant typical traditional art & crafts: innovative applications" (82/235), "Material properties: technical properties" (80/235) and "Material properties: aesthetic property" (69/235). The least useful option selected was "Introduction: what it is" (56/235), "Manufacturing process: process diagrams" (54/235), "Manufacturing process: more information" (51/235), "Manufacturing process: process" (48/235) and "Relevant typical traditional art & crafts: more information" (43/235) (Fig. 6). Responses appeared to depend on the occupation of the participants. For designers with practical experience who had understanding of the basic names and properties of materials, they thought that

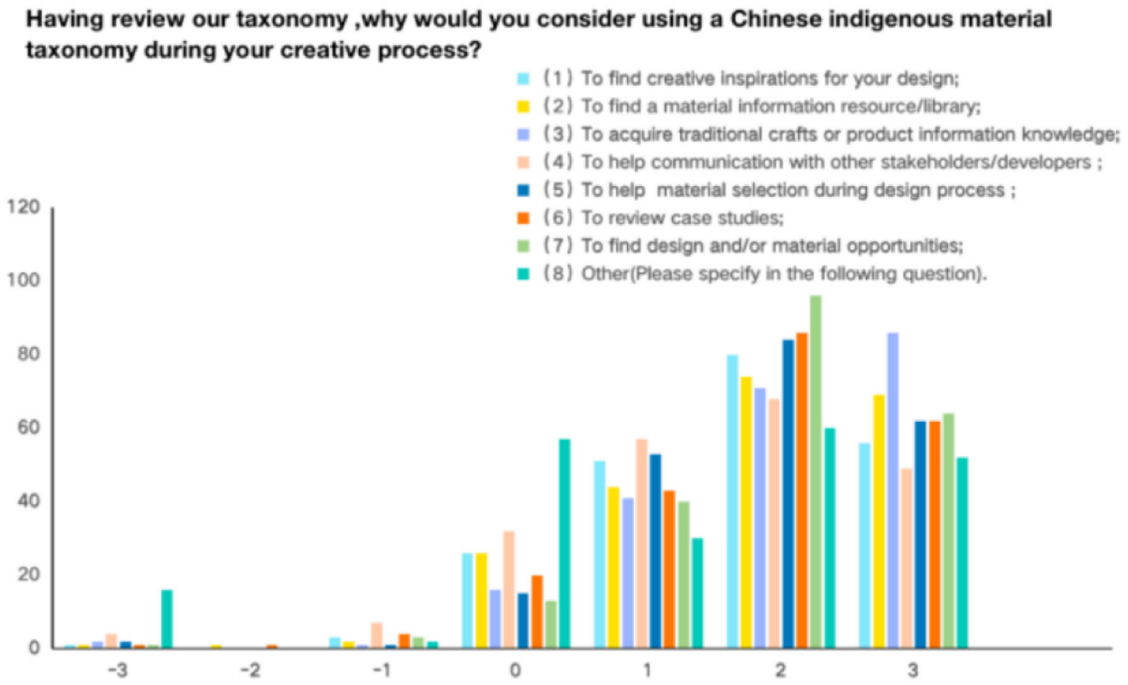


Fig. 2 Reasons for using the taxonomy. Alt Text: The figure uses horizontal and vertical coordinates to display the reasons why participants use the taxonomy. The horizontal axis is composed of −3 to 3, and the vertical axis is composed of 0 to 120. The questions include 8 items, namely, to find creative inspirations for your design; to find a material information resource/library; to acquire traditional crafts or product information knowledge; to help communication with other stakeholders/developers; to help material selection during design process; to review case studies; to find design and/or material opportunities; other(Please specify in the following question). The results are presented as a bar chart, and most scores are distributed among 1–3 points, with the 2 and 3 point options accounting for the majority.

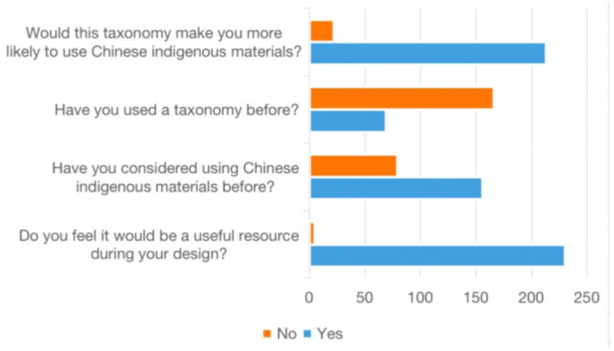


Fig. 3 Acceptance and usefulness of the taxonomy (1). Alt Text: A bar chart with the horizontal axis consists of 0–250 and the vertical axis represents participants' options (Yes or No) to four different questions. The questions and results are as follows: Would this taxonomy make you more likely to use Chinese indigenous materials (Yes 213/ No 22)? Have you used a taxonomy before (Yes 69/ No 166)? Have you considered using Chinese indigenous materials before (Yes 156/ No 79)? Do you feel it would be a useful resource during your design (Yes 230/ No 5)?

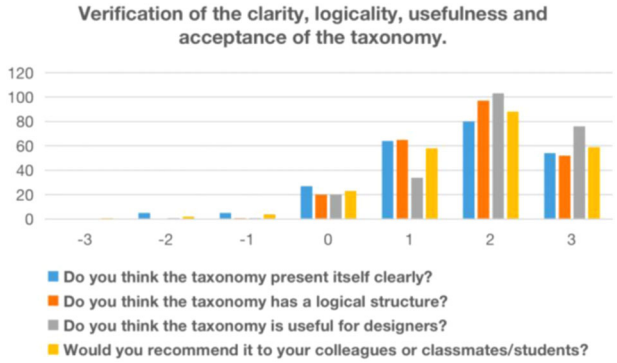


Fig. 4 Acceptance and usefulness of the taxonomy (2). Alt Text: A bar chart with horizontal and vertical coordinates to display the results of acceptance and usefulness of the taxonomy. The horizontal axis is composed of −3 to 3, and the vertical axis is composed of 0 to 120. The questions include 4 items, namely, do you think the taxonomy present itself clearly? Do you think the taxonomy has a logical structure? Do you think the taxonomy is useful for designers? Would you recommend it to your colleagues or classmates/students? The results show that most scores are distributed among 1–3 points, with the 2 points options selected at most.

the innovative application and technical properties of materials were more important for designers. For students, a basic understanding of materials (introduction, typical product design applications) was the most useful. For designers with practical experience, the introduction of the material was least useful. For students who lacked practical experience, the introduction of materials was very important and the production process of materials was least useful. The findings indicated that designers value the inclusion of case study applications for CIMs, technical properties and aesthetic properties. In terms of potential improvements for the taxonomy, the authors propose the addition of new case study applications (21), more types of material (9), the distinction of material functional attributes (5) and revising the layout to enhance interaction.

In response to feedback, each issue was addressed in the revised taxonomy by adding material information and creative

design applications, optimizing the display mode and structure logic. This included the addition of URL links for more taxons, such as websites recommended for contemporary creative design cases relative to folding paper, e.g. https://www.puchedu.cn/zhezhi/8b3290fc75770b4b.html to help experienced users quickly browse and obtain more creative case resources, stimulate their innovative inspiration, and to supporting novice users to obtain basic knowledge by providing additional typical product design applications with more images, stories, videos and websites, e.g. https://www.ihchina.cn/page_special.html.

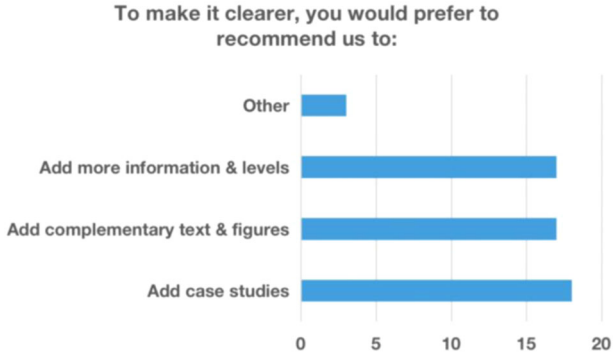


Fig. 5 Recommendations for optimization. Alt Text: A bar chart with a horizontal axis consisting of 0–20 and a vertical axis displaying the participants' recommendations to make the taxonomy clearer. The options and results are: Add case studies (18/24); Add complementary text & figures (17/24); Add more information & levels (17/24); Other (3/24).

Whilst a significant amount of information was available online this could be difficult for designers to access, especially non-Chinese designers who are not familiar with the culture but had a requirement to obtain comprehensive information on materials. This was, at least in part, due to the lack of a glossary or taxonomy for indigenous materials, including CIMs. To address this need, keyword recommendations were identified to help users conduct searches on platforms such as Pintrest, Google, Art&Culture and Behance. These keywords were mostly obtained from our previous search experience and high-frequency keywords were obtained from relevant papers on China National Knowledge Infrastructure (CNKI, www.cnki.net, the most commonly used online academic platform in China, which includes journals, dissertations, conference papers, reference books, patents, overseas literature resources, etc., has a daily updated literature volume of over 50,000 articles).

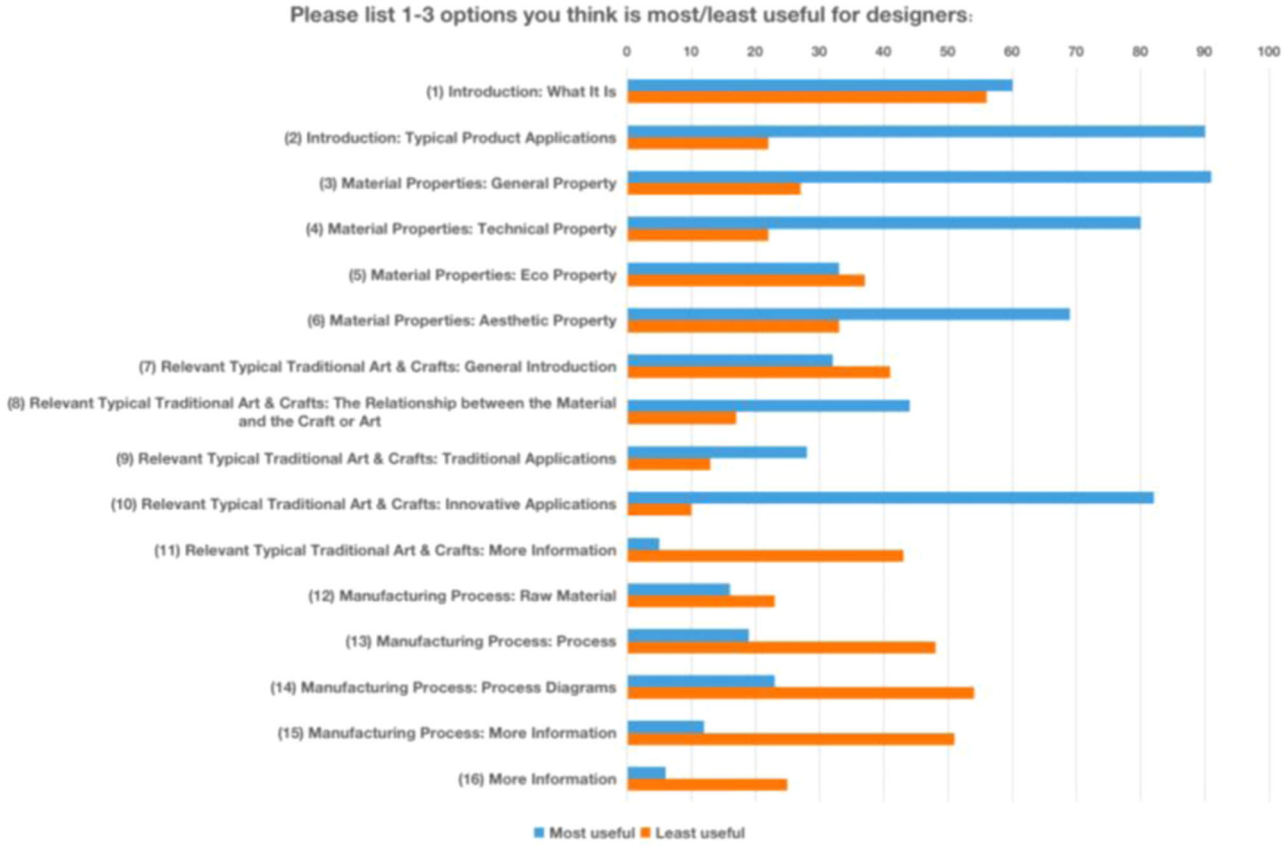


Fig. 6 Options selected as the most/least useful for designers. Alt Text: A bar chart with a horizontal axis consisting of 0–100 and a vertical axis displaying the participants' options they thought were the most useful and least useful for designers. The results show that the options selected as the most useful are "Material properties: general property" (91/235), followed by "Introduction: typical product applications" (90/235), "Relevant typical traditional art & crafts: innovative applications" (82/235), "Material properties: technical properties" (80/235), "Material properties: aesthetic property" (69/235). The least useful options selected are "Introduction: what it is" (56/235), followed by "Manufacturing process: process diagrams" (54/235), "Manufacturing process: more information" (51/235), "Manufacturing process: process" (48/235), "Relevant typical traditional art & crafts: more information" (43/235).

Conclusion

CIMs and relevant crafts are important sources of inspiration sources that are largely unused by designers. To collect, identify and classify the knowledge of CIMs and relevant crafts from the perspective of the creative needs of designers, this paper provides a framework for a taxonomy of CIMs based on a systematic literature analysis, primary data collection and resource sorting.

To verify the usefulness and acceptance of the taxonomy framework and further optimize it, expert interviews and online questionnaires for designers were conducted. The results show that most participants are willing to consider using the taxonomy framework when undertaking creative design to help identify design or material opportunities, acquire traditional crafts or product information, knowledge on professional materials and stimulate creative activities. In addition, they also feel that the framework of the CIM taxonomy encourages the use of Chinese indigenous materials and they would be prepared to recommend it to colleagues/classmates. As for the framework structure, most participants feel that the framework presented itself clearly with a logical structure. Similarly, the vast majority of participants agreed that it represents a useful classification framework for designers and list the most useful options of general properties (91/235); introduction: typical product applications (90/235); relevant typical traditional art & crafts: innovative applications (82/235); material properties: technical properties (80/235); material properties: aesthetic properties (69/235). The participants put forward suggestions for optimizing the framework.

The proposed taxonomy framework for CIMs can help designers acquire material and process information from top-down and bottom-up, providing a logical framework for the construction of a CIM-related material network resource library. Based on the taxonomy framework, it is convenient to compare materials according to various attributes and parameters and support designers in selecting materials. In addition to supporting creative activities and material selection, when designers undertake research and development of cultural and creative products for a specific CIM and its relevant crafts, they can build a basic framework, obtain a more comprehensive and clearly structured material and process knowledge framework and conduct experimental research which can be more efficient and flexible for design research. The taxonomy framework can be regarded as supporting designers to navigate, observe and invent using CIMs.

In the future, we hope to add more CIM information and creative design case studies based on this framework, further optimize the interaction and build a database of CIMs for cultural and creative product design. This will provide tools such as material selection, material exchange and inspiration for relevant design practice, teaching and research.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Author Contributions

DJ, ME, KH and IS contributed to the study's conception and design; DJ and ZB contributed to the data collection and analysis with guidance from ME; methodology was repeatedly discussed between DJ and ME; DJ led the writing and editing with the review of ME; DJ and ZB contributed to the visualization of the taxonomy; DJ, ME, KH and IS commented on previous versions of the manuscript; all authors read and approved the final manuscript.

Competing interests

The authors declare no competing interests.

Ethical approval

This study was granted an exemption from requiring ethics approval. This study does not involve sensitive ethical issues, so there is no need to apply for review by relevant academic ethics committees.

Informed consent

Informed consent was obtained from all the participants.

Additional information

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