Digital Design Process and Part Family Division of Solid Wood Custom Cabinet Door Based on Multi-attribute Overlapping Clustering Technology

Jie Ren,[a] and Xianqing Xiong [a,b,*]

The flexible production of solid wood custom furniture is needed to meet the individual needs of the market. Based on M Company, this study developed a digital design platform and its key technologies (data extraction and integration, part family division, coding technology, model base construction, information interaction, and connection) and proposed a multi-attribute overlapping clustering technology (MOCT) method for the division of a family of cabinet door parts. The results indicated that the platform and technologies based on M company provides a reference for the digital transformation of solid wood furniture. The part family division method based on MOCT displayed excellent grouping performance and adjustability, and it could be extensively applied to the group processing of solid wood furniture parts.

DOI: 10.15376/biores.17.3.5393-5419

Keywords: Multi-attribute decision-making; Clustering algorithm; Solid wood furniture; Digital design; Cabinet door

*Contact information: a: College of Furnishings and Industrial Design, Nanjing Forestry University, 210037, Jiangsu, China; b: Nanjing Forestry University, College of Furnishings and Industrial Design, Co-Innovation Center of Efficient Processing and Utilization of Forest Resources, 210037, Jiangsu, China; * Corresponding author: xiongxianqing@njfu.edu.cn*

INTRODUCTION

With the advent of intelligent manufacturing, the business model with "personalized customization" as the theme and the manufacturing model with "flexible manufacturing" as the core have entered the traditional manufacturing industry (Yang and Xiong 2022). The traditional manufacturing industry should adapt to this change with rapid transformation and upgrading to digital design and manufacturing (Wiedenbeck and Parsons 2010; Tang *et al.* 2018). Digital design includes modeling with full consideration of the entire product life cycle and the customer needs for customized products *via* the computer, network, computer-aided design (CAD), and computer-aided engineering (CAE) software, printer, plotter, and other tools (Liu *et al.* 2019). The process consists of relying on digital compression, coding, demodulation, modulation, and other processing technologies. Then, the product design is completed after certain calculations, the geometric model is constructed, and there is repeated data debugging (Yang *et al.* 2019). Research on the digital design of household products at home and abroad has focused on the standardized and serial design of products (Ren *et al.* 2022a,b). With the rapid development of customized homes and the application of various kinds of control software in household enterprises, digital design has developed in the direction of integrated technology of design, manufacturing, and management. However, there has been little systematic research on digital design technology systems for intelligent manufacturing.

Development History of Digital Design

In China, the development of household digital design and manufacturing technologies has experienced four major stages (Zhang *et al.* 2021; Xiong and Yue 2022; Wu *et al.* 2022).

The first stage

Based on the research and development of digital furniture design software, the theoretical research of software systems has achieved certain results. In this study, a computer-aided fashion design (CAFD) system for furniture parts and structures, a furniture computer aided design (FCAD) system for furniture structure design, and a CAD system for interior design and furniture modeling design were developed independently. However, due to the lack of software maintenance and technical up-grading, the scope of promotion and application remains limited.

The second stage

The introduction of design software and interface communication is the foundation for the digital transformation of China's furniture industry. AutoCAD software has been recognized by furniture enterprises because it is easy to learn and use, and it has a secondary development interface. Some kinds of cabinet design software such as KCD Cabinet Designer, Cabinet Pro, and Cabinet Vision Solid have been promoted. Due to the incompatible format, no localization, and high price, they have been only applied by a few foreign-funded or OEM companies.

The third stage

The development of digital design mainly focuses on the custom development of digital furniture design software at home and abroad. Digital design and transformation of manufacturing has become the core competitiveness for enterprises to survive and develop. Domestic software options including SAP, Oracle, Epicor, WCC, 2020, IMOS, Top-solid, Dingjie, and Jindie have become the main representatives of digital design and control systems in the industry. Special software has been developed for furniture enterprises in consideration of domestic characteristics, such as Dongguan Shufu Software and Guangzhou Liansi Software.

The fourth stage

Online displays of digital furniture designs have attracted wide attention. Considering the functional characteristics during the process of customized furniture design, domestic software enterprises have developed functional software for household digital design concerning functions such as order disassembly and rendering. Enterprises represented by Guangzhou Rhinoceros R5, Yuanfang, three-dimensional (3D) home, and Kujiale have formed a situation of domestic digital design function software. Compared with internationalized mature software and operation standards (standardized import type), domestic software, which is more suitable for the actual needs of China's furniture enterprises, has quickly opened the market of China's digital furniture design.

Application of Multi-attribute Clustering Algorithm

Multiple attribute decision making (MADM) is a method that selects the optimal scheme or ranking in consideration of multiple attributes based on the existing decision information (Zolfani *et al*. 2016). Clustering is a process of forming multiple categories from multiple physical or abstract sets according to the principle of similarity. There are various kinds of cluster analyses, mainly partitioning methods, hierarchical methods, density-based methods, grid-based methods, and model-based methods. The traditional clustering methods, which are classified by distance, could not achieve a good clustering effect for samples with multiple attributes (D'urso and Massari 2019). Therefore, the MADM model is often applied to be combined with the clustering algorithm. Multi-attribute overlapping clustering technology (MOCT) is a clustering method that includes multiple attributes of samples into the analysis. This clustering method could integrate and analyze cardinal category, ordinal category, as well as qualitative and other indexes, and interpret the clustering results and significance from numerous aspects (Liu and Shi 2017). Therefore, MOCT has been employed for analyses and evaluation, user preference, evaluation report, geographic cluster analysis and navigation, and medical analysis, among others

There are two major methods to deal with mixed data containing multiple attributes, *i.e.*, data preprocessing, which presents all variables of the same type through the common methods of binary variables and virtual coding, and dissimilarity measure, which could handle the mixed data possibly by assigning a weighting system for addressing the relevance of each attribute type (D'urso and Massari 2019). Liu and Shi (2017) put forward MOCT based on the application of the clustering analysis and compared it with the traditional methods in terms of the evaluation and analysis of urban comprehensive competitiveness in China, and the results indicated its superiority.

Other studies have combined MADM with the *K*-mean algorithm. Ma (2017) determined the importance of ranking of attributes based on users' preferences to select the cluster number *K*, which provides a new system framework for preference modeling. Rijati *et al.* (2018) applied the multi-attribute evaluation technology to quantify the factors that affect student entrepreneurship and developed weight standards, which reduces the sum of squared errors and the number of iterations com-pared with the conventional *K*-means algorithm. Liu *et al.* (2021a) considered the quality of service (QOS) objectives and customer preference attributes, quantified attribute preference through the collaborative filtering (CF) algorithm, optimized multi-attribute manufacturing service composition (MSC) *via* the third-generation non-dominated sorting genetic algorithm (PONSGA-IID), and finally recommended the most appropriate solution for customers through attribute preference sorting. Xiao *et al.* (2021) proposed a mechanical product module division method based on a spectral clustering algorithm. The correlation of parts was standardized with real numbers between zero and one and then weighted to optimize clustering. The results indicated that this method could effectively reduce the complexity of mechanical product design.

Pang *et al.* (2019) proposed a MapReduce-based subspace clustering algorithm (PUMA) to tackle the problem of high-latitude data processing. First, the co-occurrence probability of attributes in different latitudes is calculated to obtain the weight value. Next, the sub-clustering of each attribute subspace was calculated. Finally, the hierarchical clustering iteration is combined to merge the sub-clustering. This method could achieve better clustering accuracy in the expert system. Hao *et al.* (2010) proposed a multi-attribute fuzzy clustering blood vessel segmentation algorithm based on spatial continuity, which considered both intensity information and geometry information. The results indicated that this method had better quality compared with a single intensity information segmentation method.

D'urso and Massari (2019) proposed a fuzzy clustering model of mixed feature data, which fully considered different types of variables and attributes and combined different measures of each attribute through the weighting scheme to obtain the distance measurements of multiple attributes. This method has been applied to tackle the problem of the clustering of ski-lifts located in the Dolomi area and the European social survey, and the results indicated that it is very effective (D'urso and Massari 2019). Wei *et al.* (2020) developed an adaptive propagation traffic behavior recognition algorithm with multi-attribute trajectory characteristics, proposed multi-attribute similarity measurement of space, speed, and route, and combined it with a density-based clustering algorithm to provide better monitoring and navigation suggestions. Notably, the combination of MADM and clustering algorithm has been extensively applied.

The application of clustering algorithms to the furniture industry mainly focuses on the group processing of parts, and the selection of classification attributes is generally limited to craft. Previous studies respectively applied the ant colony clustering algorithm and fuzzy clustering algorithm to investigate the part classification of customized cabinets, which remarkably improved the processing efficiency of enterprises (Jia *et al.* 2016; Tao *et al.* 2020). Güven and Şimsir (2021) utilized fuzzy clustering and rank order clustering methods to create the part-machine matrix according to the production flow technique and grouped the parts and machines, which improved the productivity and reduced the cost. To optimize the production layout, Dianita *et al.* (2020) applied the rank order clustering (ROC) and Hollier method to classify the machinery and process in the production layout, successfully reducing the total travel time and distance. The classification of solid wood furniture parts is complex, and the factors that affect their production and processing include the craft, size, tongue and groove structure, and bending degree. Single attribute technology could not meet the requirements of group processing of parts design and production.

Based on the investigation of the design process and enterprises of solid wood furniture, this study put forward the steps of building a systematic standardized design platform process. Aiming at the division of the part family, which is the key node in standardized design, a classification method based on MOCT was proposed. The performance of this method was verified by the product data of solid wood cabinet doors sold in Moganshan household enterprises.

Manufacturing Status

The combination of affordable and plate cabinets with rich and diverse solid wood cabinet doors accounts for a large proportion of the diversified product line layout of cabinet furniture. However, plate cabinets only take approximately 20 d from order to package, while solid wood cabinet doors take approximately 35 d (Fig. 1). With the enterprise resource planning (ERP) system as the information transmission medium, the store designers upload drawings or models that need to be manually checked and disassembled by factory designers. The order adopts the forward arrangement method to arrange production (Li *et al.* 2018; Ma *et al.* 2020; Amaral and Peças 2021; Zhu *et al.* 2022a,b). After the survey on peer enterprises (HOLIKE, SLEEMON, MENTIAN, and A-Zenith), it was found that the production cycle of solid wood products was generally 30 d to 45 d and the production efficiency was quite low.

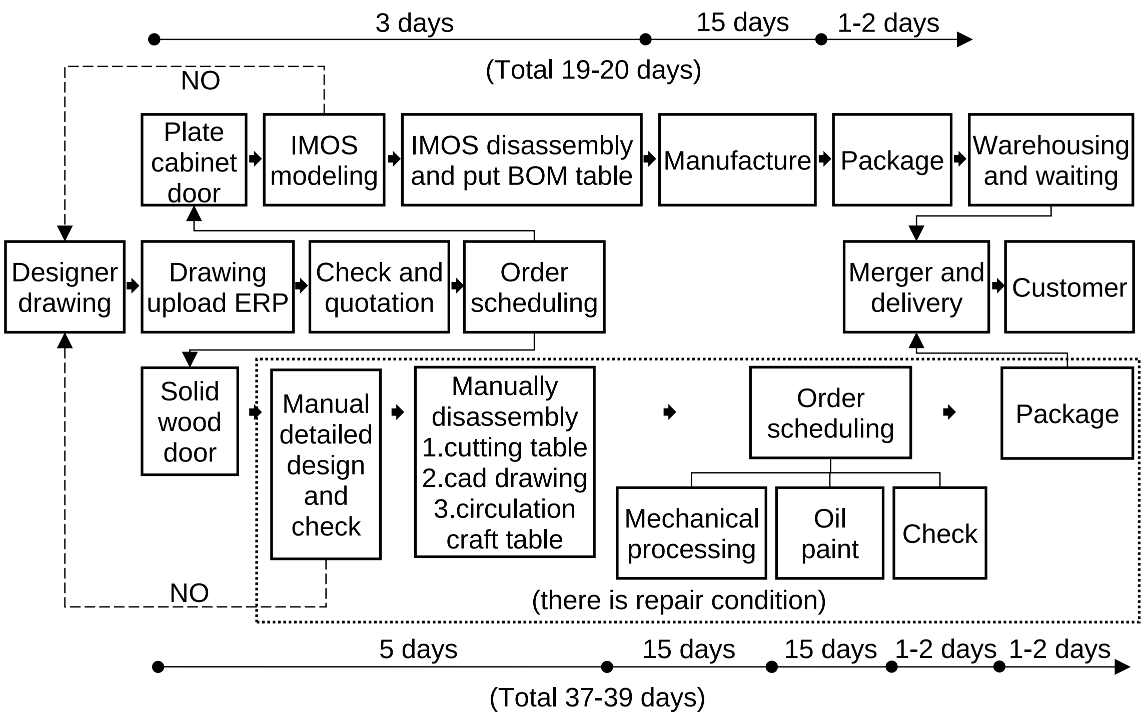

Fig. 1. The production cycle of cabinet furniture in M company

This low efficiency has two explanations. First, the product system is complex. There are various types of cabinet doors due to different modeling and functional requirements, whose parts are different in size and structure and difficult to exchange. Moreover, there are barriers between design and production. The design section mainly applies 3D software, the manufacture section mainly deals with CAD drawings, and the store section has model files only for display. When delivered to the manufacturing end, the orders are manually separated for flow production, which leads to low production efficiency.

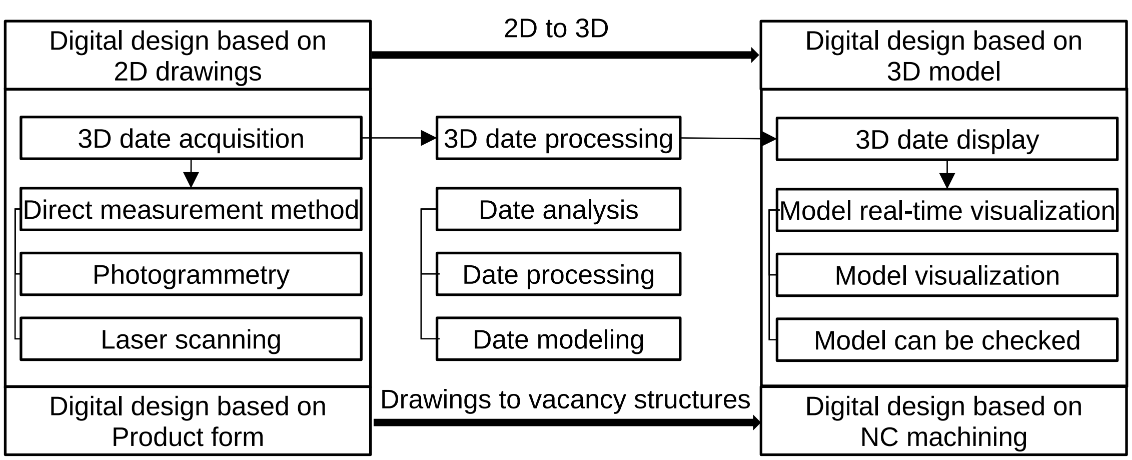

Fig. 2. The basic process of home digital design

The Basic Process of Digital Design

Home digital design refers to the application of specific 3D software tools to realize a series of digital operations such as virtual creation, modification, improvement, analysis, and display of furniture models through design data acquisition, processing, and display. The basic process is presented in Fig. 2.

Key Technologies for Building the Digital Design Platform

As the display window of digital design, the platform has key technologies including cabinet door data extraction and integration, part family division, coding technology, model base construction, as well as information interaction and connection (Kulak *et al.* 2012).

Cabinet door data extraction and integration

The cabinet door product data shall be obtained from the enterprise's CAD drawing date, design side software database (*e.g.* 2020-Design, Topsolid, and 3D +) (Hui *et al.* 2020), product display manual, product technical manual, and other paper and digital materials. The basic design data of cabinet door parts including shape, dimension parameters, tenon and groove parameters, and frame mode are collected and integrated.

Taking the 93 door types of Moganshan company as examples, the existing cabinet door data of the enterprise are cumbersome and complex. Under the same model, the sizes and structures of door and drawer panels, molding core board doors, and flat core board doors are different, which makes it difficult for the parts to be replaced and makes production more difficult. Therefore, the parts under the same model should be common to the largest extent. Under the principle of simplifying the same functional parts, the structure and size of parts are analyzed and classified. The structure directly affects the thickness of parts, so the integration order is structure and size.

Tongue and groove structure

The tongue and groove structure is reflected in the connection method between the frame board and the core board or the wood line. It is necessary to analyze and integrate the structure of the frame board, core board, and wood line. The frame board structure is related to the frame form and the wood line type. The frame form could be divided into core board embedded frame and whole panel, while the wood line type could be classified into pressing line and buckle line. Therefore, the tongue and groove style could be divided into core board embedded frame-no wood line (a), core board embedded frame-pressing line (b), and core board embedded frame-buckle line (c) (Fig. 3).

The core board is divided into "shape" and "without shape" whose thicknesses are different, but both rely on the U-shaped edge of 5 mm to lap or insert into the frame board, so their structure could be unified (Figs. 3d, 3e, and 3f). The wood line is classified into buckle and pressing. The buckle line could unify its lap depth, *i.e.* the difference value from the front of the core board to that of the frame board, which is 12 mm after integration. The total depth of the core board and the pressing line is 15 mm and the thickness of the core board is 5 mm, so the lap depth of the pressing line shall not exceed 10 mm. The line structure is presented in Fig. 4.

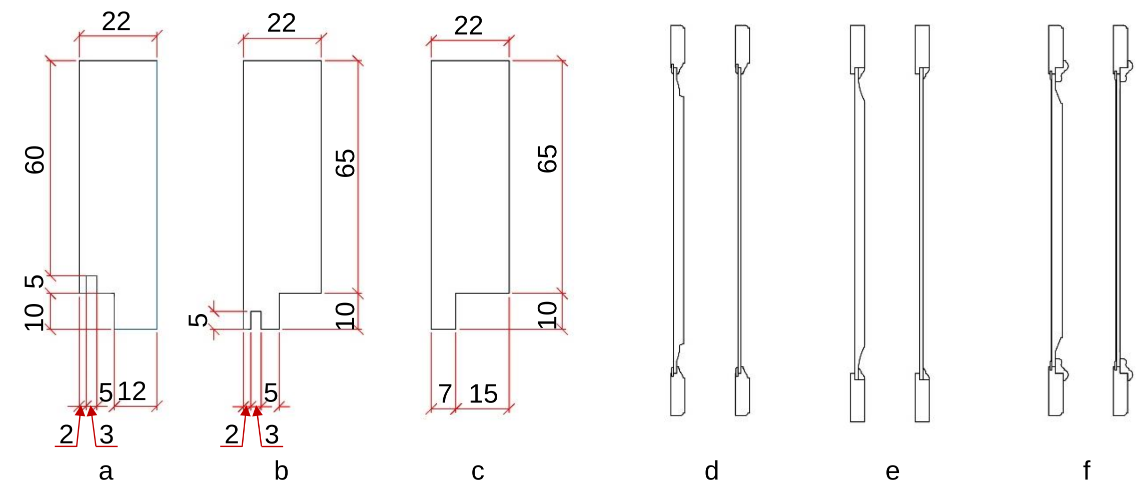

Fig. 3. The a, b, c) frame board tongue and groove structure and d, e, f) frame board and core board assembly method

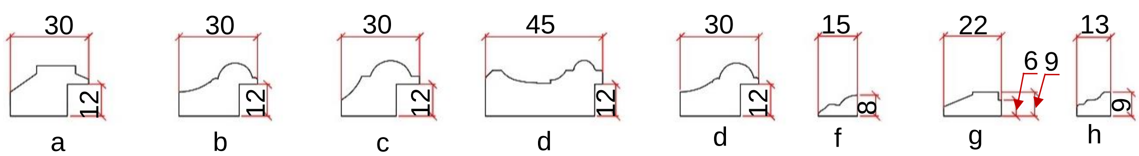

Fig. 4. Wood line structure of the a, b, c, d, e) buckle line and f, g, h) pressing line

Size integration

The cabinet door meets the changeable needs of customers by changing the length of four frame boards (upper, lower, left, and right), the length and width of the core board, and the length of the wood line and stuck line. Therefore, it is necessary to unify the width and thickness of four frame boards, the width and thickness of the middle frame board, and the thickness of the core board to improve standardization. There are three size optimization principles. First, the value with the largest proportion of part size is taken as the optimization object. Second, parts of the same structure and function should keep the same size to the largest extent. Third, the structure and size of the drawer panel and the door panel shall be consistent as much as possible, and the door panel shall be the main integration.

Table 1. Thickness Size Distribution

Thickness (mm)	5	9	10	12	15	18	20	21	22	23	Nothing	4 (Glass)
Four Frame Boards	0	6	0	0	0	0	3	3	52	1	28	0
Middle Frame	0	0	0	0	0	0	10	0	44	0	39	0
Core Board of Door	5	6	18	1	25	6	5	2	23	0	0	2
Core Board of Drawer	5	6	16	1	6	2	25	0	22	0	10	0
Total	10	18	34	2	31	8	43	5	141	1	77	2

Thickness

The thickness of the four frame boards and the middle frame board shall be consistent to facilitate the structural insertion, of which 22 mm accounts for the most. The thickness of the raw material is distributed within the approximate range of 24 mm to 26 mm, which could maximize the use of raw materials, so the thickness of the four frame boards is combined into this value. The thickness of the core board is the same as the structure with a molding door panel of 15 mm and a flat door panel of 5 mm.

Table 2. Width Size Distribution

Width (mm)	26	50	52	55	57	59	60	65	70	75	78	80	90	95	100	Nothing
Drawer Upper Frame	1	5	0	25	0	0	2	2	1	8	0	9	0	0	0	40
Drawer Lower Frame	1	5	0	34	0	0	2	2	1	8	0	0	0	0	0	40
Door Upper Frame	6	0	1	2	1	1	3	2	6	34	0	0	0	0	9	28
Door Lower Frame	6	0	1	2	1	1	3	2	6	43	0	0	0	0	0	28
Left and Right Frame	6	0	3	0	0	0	2	2	6	46	0	0	0	0	0	28
Middle Frame	0	0	0	0	0	0	3	3	0	0	3	0	33	7	5	39
Total	20	10	5	63	2	2	15	13	20	139	3	9	33	7	14	203

Width

Part of the door type has a bending shape, so the upper and lower frames are different from the left and right frames. Under the same type, the left and right frames of the drawer panel and door panel are the same. The top three width dimensions are 55, 75, and 90 mm. The left and right frames widths are 75 mm, and they account for the largest proportion, so the left and right frames widths on the door panel and drawer panel are merged with this value. The 55 mm dimension is mainly distributed on the upper and lower of the drawer panel. Because the drawer panel is small, a large size of the upper or lower frame will affect the shape of the core board, so the size of upper and lower frames on the drawer panel is maintained at 55 mm. There are bending-shaped doors on the upper frame board, and the width of upper and lower frames on the drawer panel is uniformly 75 mm, while that on the door panel is 90 mm. The middle board needs to have upper and lower tongues and grooves prepared. If the size is the same as the upper and lower frames, then the visible width after slotting will be less than that of the upper and lower frames, which will affect the beautiful proportion. So the largest proportion number (90 mm) is taken as the merged target value. The door type produced by other factories shall retain its decorative frame board size, and the width of the frame board shall be 26 mm.

Part family division

The upper limit of cabinet door derivative design depends on whether the division of product parts family is fine. Based on complete door data collection, the cabinet door is disassembled into single parts. The part family classification of solid wood could be affected by various indexes, four essential indexes are extracted, i.e. size, craft, tongue, and groove structure, and bending degree, which are divided by MOCT (Du *et al.* 2020; Tao *et al.* 2020; Xiong *et al.* 2021), as described in detail in next section.

Coding techniques

As the basic data of enterprise production and manufacturing, the code of cabinet door parts is also the key link to realizing the tracking and retrieval of cabinet door parts (Gong *et al.* 2019). Following the principles of uniqueness, practicability, expansibility, and standardization, the product information code and part processing information code of cabinet door are formulated in the coding mode of "identification code + classification feature code + size code." Among them, there are more surface material features of the cabinet door, so its material feature code is formulated separately (Fig. 5).

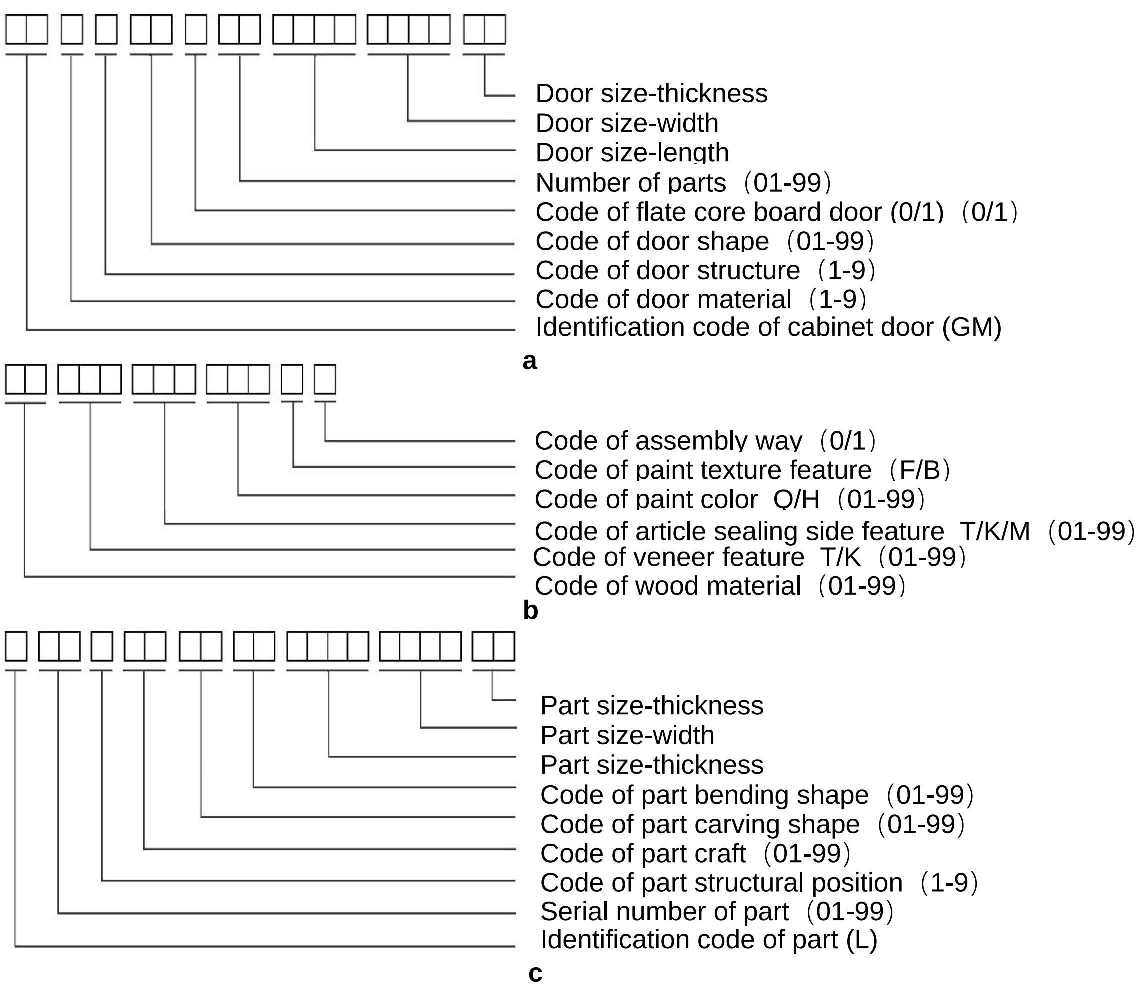

Fig. 5. The a) cabinet door information code, b) cabinet door material feature code, and c) part processing information code

The cabinet door information code mainly highlights the overall attribute and size, including the main shape and size information of the cabinet door product. The cabinet door material feature code is applied to be combined with the cabinet door information code, including the material feature attribute, assembly way, and the total number of product parts. The part processing information code is mainly utilized for the production end, *e.g.* part identification, serial number, structural position, process, carving shape, bending shape, and size information. The cabinet door size and part size often change, so intuitive embodiment on the code could increase information processing efficiency.

Model base construction

In the original database, the cabinet door takes the whole door as the smallest unit during the process of design and production, which only changes its length and width but could not achieve automatic disassembly and output BOM table with the disassembly section. Therefore, it is necessary to build a model base with parts as the minimum unit, whose construction includes two major aspects, such as the formulation of size constraint relation and the parametric module making through programming technology.

For the analysis and formulation of the size constraint relation, the essential parameter assignment of parts includes the length and width range of cabinet doors, the connection gap between door leaves, the width and thickness of parts, and the structure and size of tongue and groove. The size constraint relationship among parts is presented in Table 3.

Table 3. Size Constraint Relations of the Cabinet Door Parts

<table>
<tr><th>Part</th><th>Length</th><th>Width</th><th>Thickness</th><th>Instruction (mm)</th></tr>
<tr><td>Door panel</td><td>H1</td><td>W1</td><td>D1</td><td rowspan="7">Single door connection gap:5
double doors connection gap:4
multi-door:3
proportion:1/2,6/4
a:55,75,90
b:22
c:5,15
d:13,15,22,30,45
f:12</td></tr>
<tr><td>Upper frame</td><td>H2=W1-2(width of left/right frame)+2(depth of the tongue and groove)+ allowance</td><td>W2= a+ allowance</td><td>D2= b</td></tr>
<tr><td>Lower frame</td><td>H3=H2</td><td>W3= a+ allowance</td><td>D3= b</td></tr>
<tr><td>Left / right frame</td><td>H4=H1+ allowance</td><td>W4= a+ allowance</td><td>D4= b</td></tr>
<tr><td>Core board</td><td>H5=H1-width of upper frame-width of lower frame+2 (depth of the tongue and groove)-activity allowance+ allowance
H5= proportion(H1- width of upper frame - width of lower frame - width of middle frame)+2 depth of the tongue and groove—activity allowance+ allowance</td><td>W5=W1-2(width of left/right frame)+2(depth of the tongue and groove)- activity allowance+ allowance</td><td>D5= c</td></tr>
<tr><td>Middle frame</td><td>H6=H2(H3)</td><td>W6=d+ allowance</td><td>D6= b</td></tr>
<tr><td colspan="4">*In the 3D model stage, the allowance needs to be removed from the dimensional relationship of each part.</td></tr>
</table>

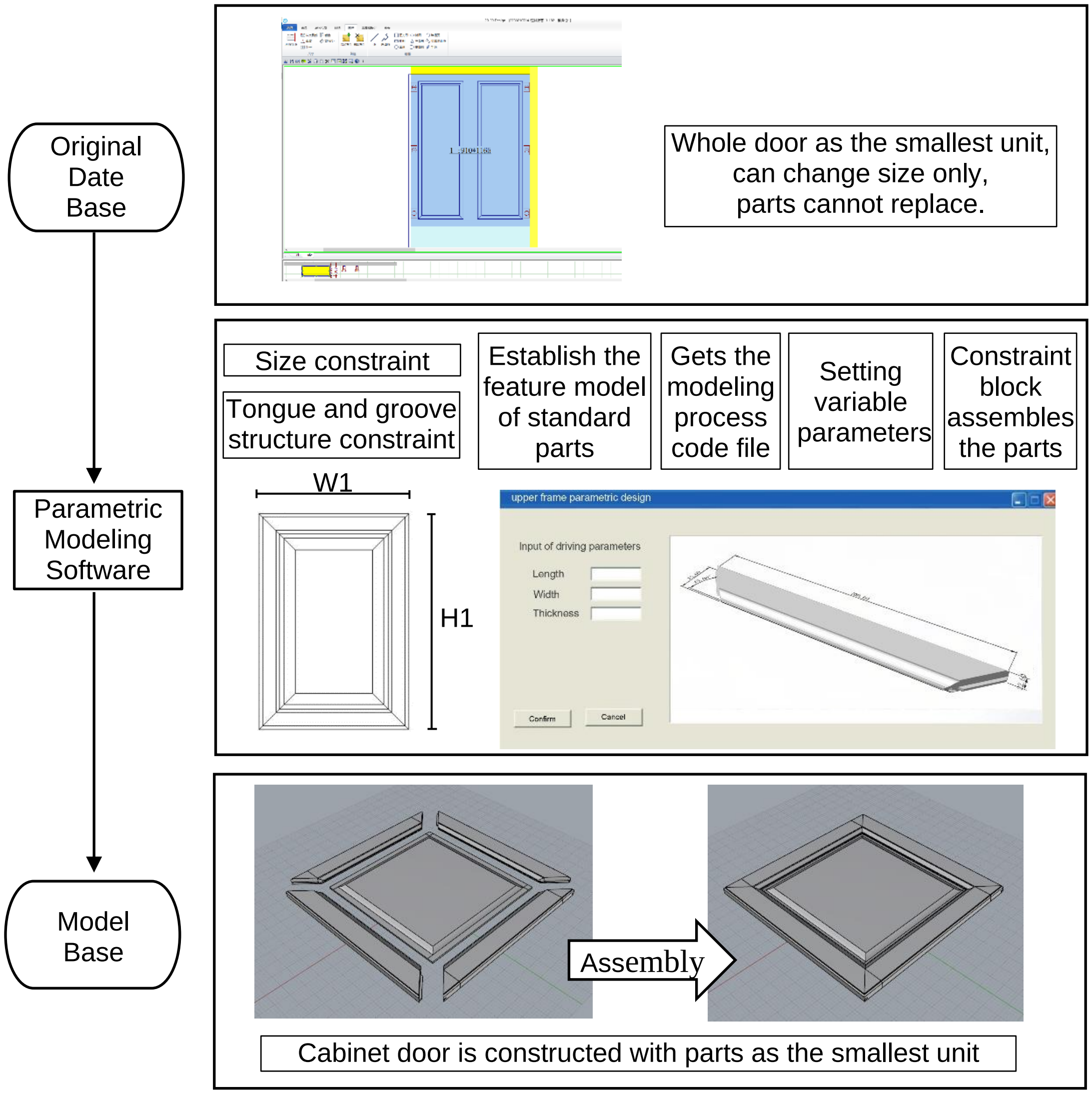

Fig. 6. Model base construction process

Various standard component models could be established *via* parametric design modeling software (*e.g.* UG NX and SOLIDWORKS) (Zhou and Zang 2020). The steps include formulating the part structure size, applying the macro recording to save its code file, and utilizing programming software to set its variable size as modifiable and obtainable, thus realizing the position relation of the assembly structure of each part of the cabinet door through constraint block. The key lies in the disassembly and reorganization of various parts and fast positioning through connected points or surfaces (Fig. 6).

Information interaction and connection

Design information needs to establish information loops in both directions with ERP software, production data management (PDM), and manufacturing execution system (MES) to connect the whole product lifecycle management (PLM) process of the enterprise (Gong *et al.* 2019). Local area network (LAN) is applied to build software sharing ports for the design section, disassembly section, and manufacturing section (Guo *et al.* 2018; Xiong *et al.* 2020; Liu *et al.* 2021b). Each equipment shall possess the cloud storage and processing functions, reduce the phenomenon of two-dimensional (2D) drawings and other engineering data throughout the whole situation, ensure smooth data flow, and reduce the cost of information interaction. In reality, this method could reduce the error rate and labor cost. The ERP system should be applied to track and trace the global data information efficiently, realize the transparency of internal data, and enhance the interconnection of various departments. Applying internet of things technology, sensing technology, monitoring technology, and logistics control technology to develop mobile terminal software that realizes real-time tracking and control of products to serve the whole production and sales cycle of products (Fig. 7) (Chen 2020).

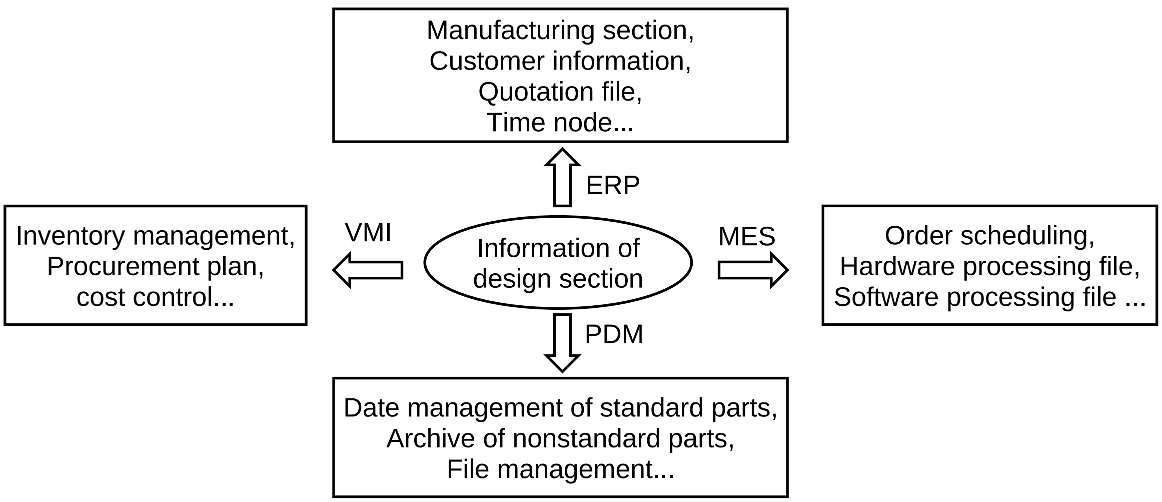

Fig. 7. Design information interaction diagram

EXPERIMENTAL

The key step of digital design is the division of the part family. A part family division method based on MOCT is proposed to tackle the complex situation of group machining of solid wood parts. This method is verified by taking over 40 solid wood door panels of M company as the test object.

Method

This study applied MOCT. First, four attribute indexes of solid wood custom cabinet door part family division (size, craft, tongue, groove structure, and bending degree) were selected (Song *et al.* 2016; Hu and Guan 2020). Next, single index analysis and clustering were conducted. Finally, the part family was determined by overlapping synthesis according to the weight ordering of the four indexes. The research sequence of this test was weight sorted by four indexes, single index clustering, and part family division.

Index weight sorting

The attribute sorting was determined by the analytic hierarchy process (AHP) and scored by experts. On a one to five scale, one denotes the least importance and five represents the greatest importance. Ten experts were counted.

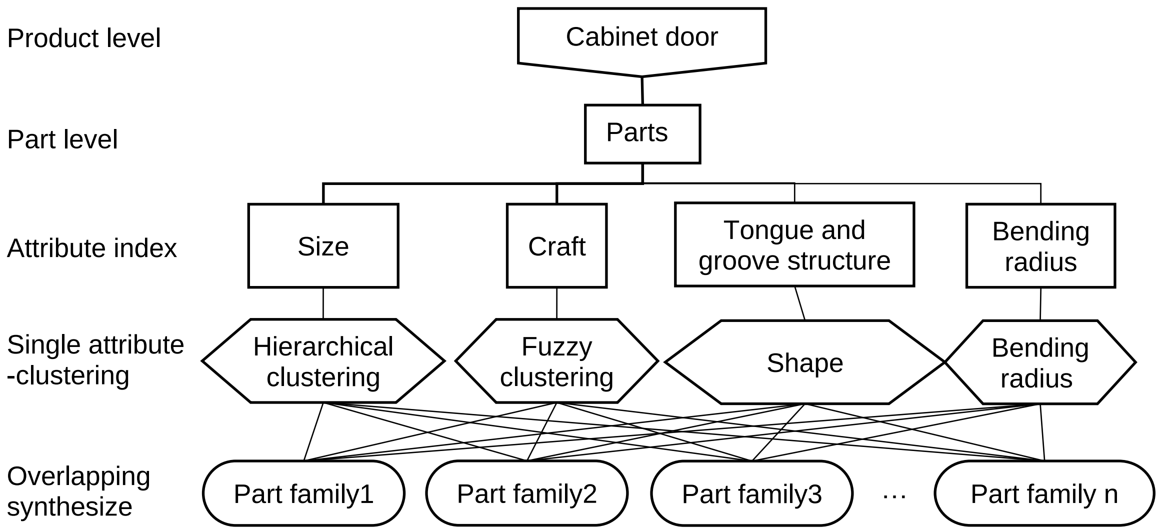

Fig. 8. Part family division steps based on MOCT

Single index clustering-size

The agglomerative hierarchical clustering method is applied to classify the parts (Lv *et al.* 2019). To do this, count the orders in 2020, take the size modes of all types of doors as the test data, and disassemble them into the size of each part (upper frame, lower frame, left frame, right frame, core board, wood lines, wood louvers, louver frame lines, and whole panel). The size data of parts is defined as a set of points in 3D space, and the similarity between parts is determined by calculating the distance between the points (Liu *et al.* 2020). The smaller the distance, the higher the similarity. The relatively close data points or categories are grouped. The length, width, and thickness of the disassembled part A as x, y, and z values in space are defined. The maximum normalization method is applied to standardize the data. The standardized x, y, and z are defined as x_{st}, y_{st}, and z_{st}, as shown by Eq. 1,

$$x_{st}=\frac{x}{x_{max}},y_{st}=\frac{y}{y_{max}},z_{st}=\frac{z}{z_{max}},x_{st},y_{st},z_{st}\in[0,1] \tag{1}$$

The similarity between standardized part A (x_A, y_A, and z_A) and part B (x_B, y_B, and z_B) is measured by the square Euclidean distance. The distance between A and B is defined as d_{AB} as shown by Eq. 2,

$$d_{AB}=(x_a-x_B)^2+(y_A-y_B)^2+(z_A-z_B)^2,d_{AB}\in(0,3) \tag{2}$$

Data points or categories with similar distances are merged into groups. The average distance between categories is utilized to measure the distance between groups. Similar categories are merged, and the clustering results are determined in line with the needs.

Single index clustering-craft

Craft clustering mainly aims at the machining section to build the part-craft matrix (Jia *et al.* 2016; Wu 2019). Some parts have the same craft, and under the same craft, the part with the smallest serial number is taken as the sample for the subsequent test. The similarity coefficient matrix is constructed through the fuzzy clustering method, and the transfer closure is calculated. Combined with the actual production situation, the appropriate clustering results are selected. The first step is to build the part-craft matrix. The unclassified furniture parts are defined as $A_n = \{a_1, a_2 \ldots, a_n\}$ and the production craft of cabinet doors is defined as $B_n = \{b_1, b_2 \ldots, b_n\}$. The structure of the part-craft matrix can be calculated by Eq. 3,

$$E_{nm} = \begin{bmatrix} e_{11} & \cdots & e_{1m} \\ \vdots & \ddots & \vdots \\ e_{n1} & \cdots & e_{nm} \end{bmatrix}, e_{nm} = \begin{cases} 1, \text{If the part } a_n \text{ is processed on craft } b_m; \\ 0, \text{If the part } a_n \text{ is not processed on craft } b_m; \end{cases} \tag{3}$$

The next step is to construct the part similarity coefficient matrix. The similarity coefficient between the two parts is determined by the maximum and minimum method based on the collected part-craft matrix. The similarity coefficient of part *i* and part *j* that belong to two different parts in A_n is denoted by x_{ij}. Craft *k* belongs to production craft B_m, e_{ik} represents the value of part *i* on craft *k*, and e_{jk} signifies the value of part *j* on craft *k*, as shown by Eq. 4,

$$x_{ij} = \frac{\sum_{k=1}^{m}(e_{ik} \cap e_{jk})}{\sum_{k=1}^{m}(e_{ik} \cup e_{jk})}, i = a_i \in A_n, j = a_j \in A_n, k = b_k \in B_m, k \in \{1,2 \ldots, m\} \tag{4}$$

The similarity coefficient could be comprehended as x_{ij} = number of crafts jointly owned by part *i* and part *j* (the number of crafts jointly owned by part *i* and part *j* + crafts with part *i* not part *j* + crafts with part *j* not the part *i*). Therefore, the greater the proportion of crafts owned by both parts, the greater the similarity coefficient. Given the above, the similarity matrix between parts is constructed by Eq. 5,

$$X_{ij} = \begin{bmatrix} x_{11} & \cdots & x_{n1} \\ \vdots & \ddots & \vdots \\ x_{1n} & \cdots & x_{nn} \end{bmatrix} \qquad x_{ij} = x_{ji}, x_{ij} \in [0,1] \tag{5}$$

The next step is to calculate the transitive closure. The constructed part similarity coefficient matrix X_{ij}, which is a square matrix, satisfies symmetry and reflexivity. The fuzzy equivalent matrix *T* is obtained through the transfer closure method. Starting from the fuzzy similarity matrix *X*, the square values of X^2, X^4, X^8,…X^R are found in turn. When X^R is equal to X^{2R}, and X^R denotes the obtained fuzzy equivalent matrix *T*, $T = (t_{ij})_{n \times n}$.

Next, the number of groups is determined by the threshold λ. The grouping conditions under different thresholds could be obtained by the interception of the threshold λ in the fuzzy equivalent matrix *T*, and then T_λ is the λ block matrix of *T*. After different clustering results are counted, its dynamic clustering diagram is obtained through Eq. 6,

$$\forall \lambda \in [0,\ 1], T_\lambda = (t_{ij}^{(\lambda)}), t_{ij}^{(\lambda)} = \begin{cases} 1, & t_{ij} \geq \lambda \\ 0, & t_{ij} \leq \lambda \end{cases} \quad i, j \in \{1, 2, \ldots n\} \tag{6}$$

Finally, calculate the similarity coefficient within the group. Various grouping methods could be obtained through the interception of the threshold λ. The craft similarity of parts in the group is intuitively judged by the average similarity coefficient in each group C_z and the mean intra-group similarity coefficient C_p. The larger the C_p value, the higher the mean intra-group similarity coefficient and the better the grouping effect. The formulas for C_z and C_p are shown by Eqs. 7 and 8, respectively,

$$C_z = \frac{\sum_{i \in H} \sum_{j \in H} x_{ij}}{h^2} \tag{7}$$

$$C_p = \sum_1^g \frac{C_z}{g} \tag{8}$$

At a certain threshold λ, the sample is divided into g groups. There are g average similarity coefficients, *i.e.* C_{z1}, C_{z2},…,C_{zg}. The number of parts in each group after grouping is denoted by h, and H represents the part set in the group after grouping, $i, j \in H$.

Single index clustering-tongue and groove structure

By analyzing the connection type of parts, the connection structure mainly includes four frame boards and core boards, four frame boards, and a wood line. Therefore, the tongue and groove structures of four frames, core board, and wood line need to be analyzed (Huang and Xu 2019; Fang *et al.* 2020), and the similar tongue and groove structures of parts should be integrated.

Single index clustering- Bending degree

Among the parts, only the upper frame has a bending shape. Therefore, this step mainly analyzes the parts with bending shape in the upper frame and divides them into categories according to the bending radius and the corner radian radius.

Part family division

The clustering results of each attribute index are sequenced according to the classified categorical character strings, and all indexes are included in multi-attribute overlapping clustering. The parts with the same character strings are classified into one family, and the total number of the different character strings is the number of families for part division.

Fig. 9. Forty types of customized solid wood cabinet doors

Samples

Forty types of customized solid wood cabinet doors (26 types of log cabinet doors and 14 types of composite solid wood doors produced by the Shenghua Yunfeng Moganshan Whole Wood Factory in Huzhou, China), are shown in Fig. 9. Flat core board, composite core board, composite flat door, and log flat plate door are the samples. The door shape is also presented in Fig. 9. After disassembly, there were 458 parts in total. After plastic stuck lines and hardware decorative lines were removed, there were 314 solid wood parts including 205 solid wood parts with different shapes and structures, which were taken as the test samples.

RESULTS AND DISCUSSION

Index Weight Sorting

The scores of 10 professional experts are counted and presented in Table 4. Firstly, the average value of each analysis item is calculated, and the judgment matrix is obtained by dividing the average value, which is constructed by SPSSAU. A higher average means a higher importance. The judgment matrix is shown in Table 5. According to the table, the average size is 5, the average value of mortise and groove structure is 4.2, the average value of process is 4.4, and the average value of curvature is 2.4.

Table 4. Evaluation Table of the 10 Practitioners

Serial Number	Size	Tongue and Groove Structure	Craft	Bending Degree
1	5	4	5	1
2	5	4	4	3
3	5	4	4	2
4	5	4	5	2
5	5	5	5	2
6	5	5	4	1
7	5	4	5	2
8	5	5	4	3
9	5	4	3	4

Table 5. AHP Judgment Matrix

Average Value	Item	Size	Tongue and Groove Structure	Craft	Bending Degree
5	Size	1	1.19	1.136	2.083
4.2	Tongue and Groove Structure	0.84	1	0.955	1.75
4.4	Craft	0.88	1.048	1	1.833
2.4	Bending Degree	0.48	0.571	0.545	1

Secondly, although the AHP method is suitable for expert scoring weight calculation, in order to avoid logical errors between attributes, a consistency check is required. The fourth-order judgment matrix is constructed, and the sum-product method is used to calculate and study, as shown in Table 6. The eigenvectors obtained from the analysis are 1.25, 1.05, 1.1, and 0.6. Combined with the eigenvectors, the maximum eigenvalue can be calculated as 4, and then the CI value is calculated by using the maximum eigenvalue. The CI value is used for the following consistency test.

Table 6. Level Analysis (AHP) Results

Attribute Indexes	Eigenvector	Weight (%)	Maximum Eigenvalue	CI
Size	1.25	31.25	4.000	0.000
Tongue and groove structure	1.05	26.25		
Craft	1.10	27.50		
Bending degree	0.60	15.00		

Table 7. Random Consistency RI Table

N Order	3	4	5	6	7	8	9
RI	0.52	0.89	1.12	1.26	1.36	1.41	1.46

The consistency test needs to use two index values, CI and RI. The CI value has been calculated to be 0.00, and the RI value can be found in Table 7 to be 0.89. CR=CI/RI. Generally, the smaller the CR value, the better the consistency of the judgment matrix. When the CR value is less than 0.1, the judgment matrix satisfies the consistency test. The CR value is 0, which means that the judgment matrix of this study satisfies the consistency test. Therefore, the experts scored the four attributes in order of weight: size, craft, tongue and groove structure, and bending degree.

Single Index Clustering-Size

The length, width, and thickness sizes of 205 parts are presented in Table 8. SPSS software (IBM, Armonk, NY, USA) was utilized for standardization and the distance between the parts was measured. After the hierarchical relationship was determined according to the similarity, the initial cluster number was eight. Combined with the actual functional types, the final cluster number was four and the shape of each classified part was described. The family tree diagram was too long, so it is omitted herein.

Table 8. Part Size Data

Sample Serial Number	Parts Name	Length (mm)	Width (mm)	Thickness (mm)
1	CYS004 left and right frame	809	77	22
2	CYS004 upper frame	263.5	77	22
3	CYS004 lower frame	263.5	77	22
⋮	⋮	⋮	⋮	⋮
205	Log flat panel door	1,416	408.5	22

The sizes are divided into four categories, the distribution of parts in each of which is presented in Table 9. Category A includes all four frames, some wood lines, and a whole panel, which are all wide and long materials that are largely different in length, width, and thickness. Category B includes some wood lines, wood louvers, and louver frame lines, which are slender materials with similar widths and thicknesses and remarkably different lengths and widths. Category C includes all core boards, some whole panels, composite panel door, and log flat panel door, which are plate parts with similar widths and lengths and significantly different widths and thicknesses. Category D is the grid line.

Table 9. Size Clustering Results

Category Code	Part Name	Description
A	All four frames, wood lines CYS0 (04/24/24F/29/29F/59), and CYS051 whole panel	Wide and long material
B	Wood line CYS0 (40/43/44/45/46/48/49/53/61), CYS015 wood louvers, and CYS015 louver frame lines	Slender materials
C	All core boards, whole panel CYS0 (67/68/60), composite panel door, and log flat panel door	Plate material
D	CYS052 grid line	Grid line

Single Index Clustering-Craft

There are 33 statistical craft routes, as indicated in Table 10. C-language programming was utilized for the auxiliary calculation. The similarity coefficient matrix of 33 × 33 was constructed and the transitive closure matrix was calculated. The calculation of $R^{32}=R^{64}$ was conducted five times to obtain the fuzzy equivalent matrix. The matrix was intercepted using different thresholds of λ, and a total of 15 clustering results were obtained. The number of groups and mean intra-group similarity coefficient C_p under different thresholds are presented in Fig. 10.

Table 10. 33 Representative Parts-Craft Matrix

Craft Serial Number	1	2	3	···	33
Sample serial number	41	51	33	···	43
Part name	CYS024 wood line	CYS029 wood line	CYS015 louver frame lines	···	CYS024F core board
Splice	0	0	0	···	1
Cut	0	0	1	···	1
Seal inside edge	0	0	0	···	0
Slotting (four side molder)	0	0	0	···	1
Slotting (CNC)	0	0	0	···	1
Assemble	0	0	0	···	0
Polish	0	0	1	···	1
Paste veneer	0	0	0	···	0
Fine cut	0	1	1	···	1
Seal outside edge	0	0	0	···	0
Mill shape	0	0	0	···	0
Mill (CNC)	0	0	0	···	1
Carve	0	0	0	···	1
Engrave and mill	0	0	0	···	0
Nail line	1	1	0	···	0
Hinge hole	1	1	0	···	0

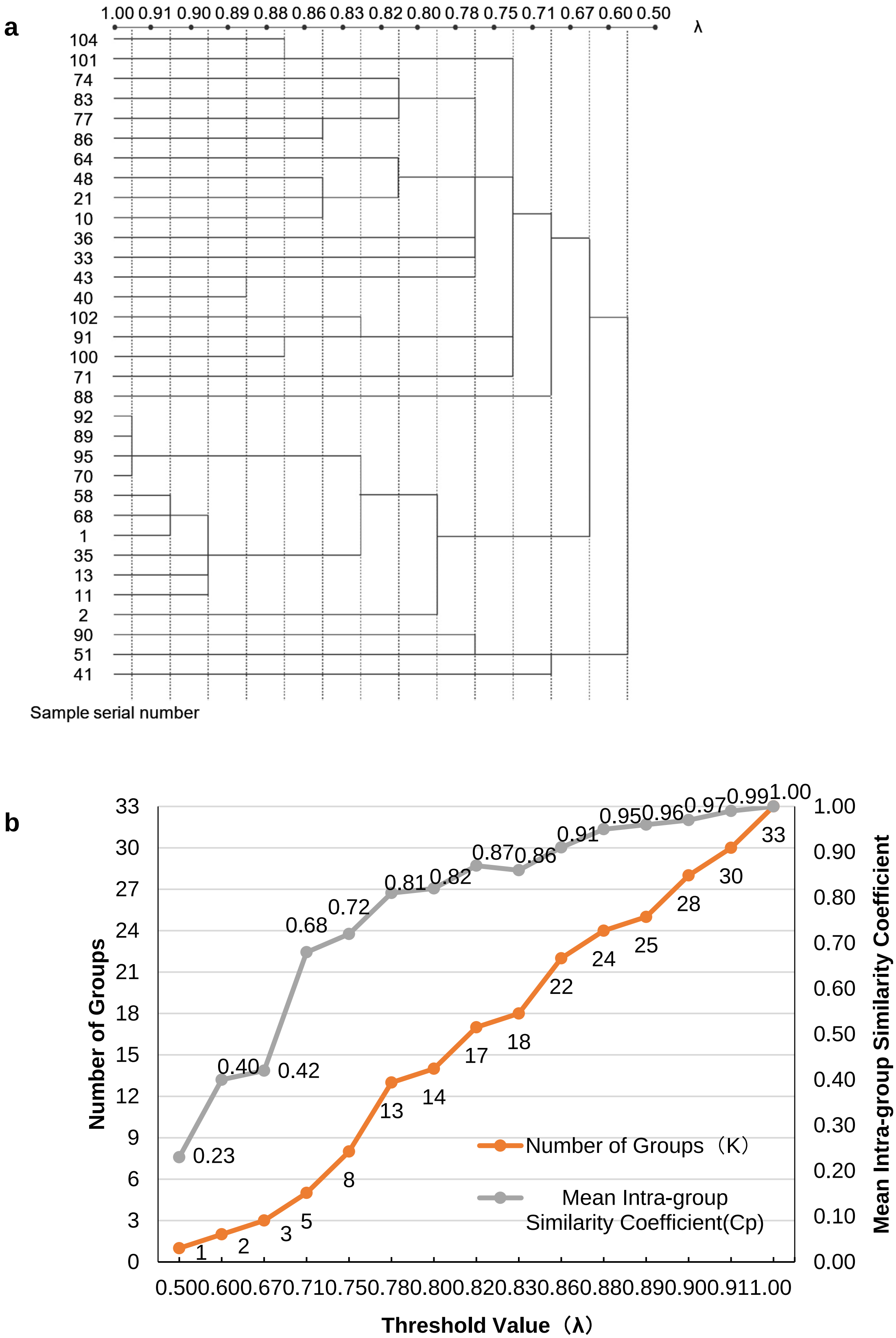

Fig. 10. The a) tree spectrogram of grouping under threshold and the b) number of groups under different thresholds and the average similarity coefficient within the groups

As indicated in Fig. 10b, the number of groups and the mean intra-group similarity coefficient gradually increased as the threshold rose. Combined with the actual production of M company, there is only one cabinet door production line, in which there will be no more than two pieces of equipment with the same function on the production line. Hence, the scheme with a small number of groups should be selected on the node with the fastest growth rate of mean intra-group similarity coefficient in the group. Therefore, in the craft grouping, the data node should be selected when λ is equal to 0.71 and there are five groups. The grouping results are presented in Table 11.

Table 11. The Craft Clustering Results

Category Code	Part Name	Description
A	All four frames	Conventional four frames craft route
B	Wood line CYS0 (04/24/24F/43/44/45/46/48/49/61)	Nail line route
C	Wood line CYS0 (29/29F/40/53/59), and CYS052 grid line	First fine cutting after the nail line route
D	Whole panel CYS051	Slotting for metal line route
E	All core boards, CYS015 louver frame lines, CYS015 wood louvers, whole panel CYS0 (60/67/68), composite panel door, and log flat panel door	Milling route

The process is divided into five categories. Category A contains all four frames and follows the conventional craft route. Category B includes some wood lines and adopts the nail line route. Category C refers to some wood lines and grid line, fine cutting after the nail line route is adopted. Category D refers to the whole panel CYS051 and adopts the metal line route. Category E includes all core panels, louver strips, wood louvers, louver frame lines, and the flat whole panel and the milling route is adopted.

Single Index Clustering- Tongue and Groove Structure

After the structure of the part is integrated with the same function of 40 door types, it is found that the tongue and groove structure mainly refers to the connection mode between the four frames and the core board, stuck line, and wood line. The four frames are the key modeling structure material in the cabinet door whose tongue and groove structure is determined by whether there are wood lines and line styles. Wood lines are divided into two types, namely the F buckle line and the G pressing line. Therefore, the four frames tenon structure connected with it could be divided into three types, *i.e.* a wireless line structure (A), a buckle line structure (B), and a pressing line structure (C). In addition, there is the whole panel structure (D) and the core board structure (E), as shown in Fig. 11. Although there are two thicknesses, *i.e.* the flat core board of 5 mm and the molding core board of 15 mm, the joint thickness connected with the frames is 5 mm, so its tongue and groove structure could be unified into one. The structures of special parts of grille door type and shutter door type are inconsistent, which are classified as category H. The clustering results are presented in Table 12.

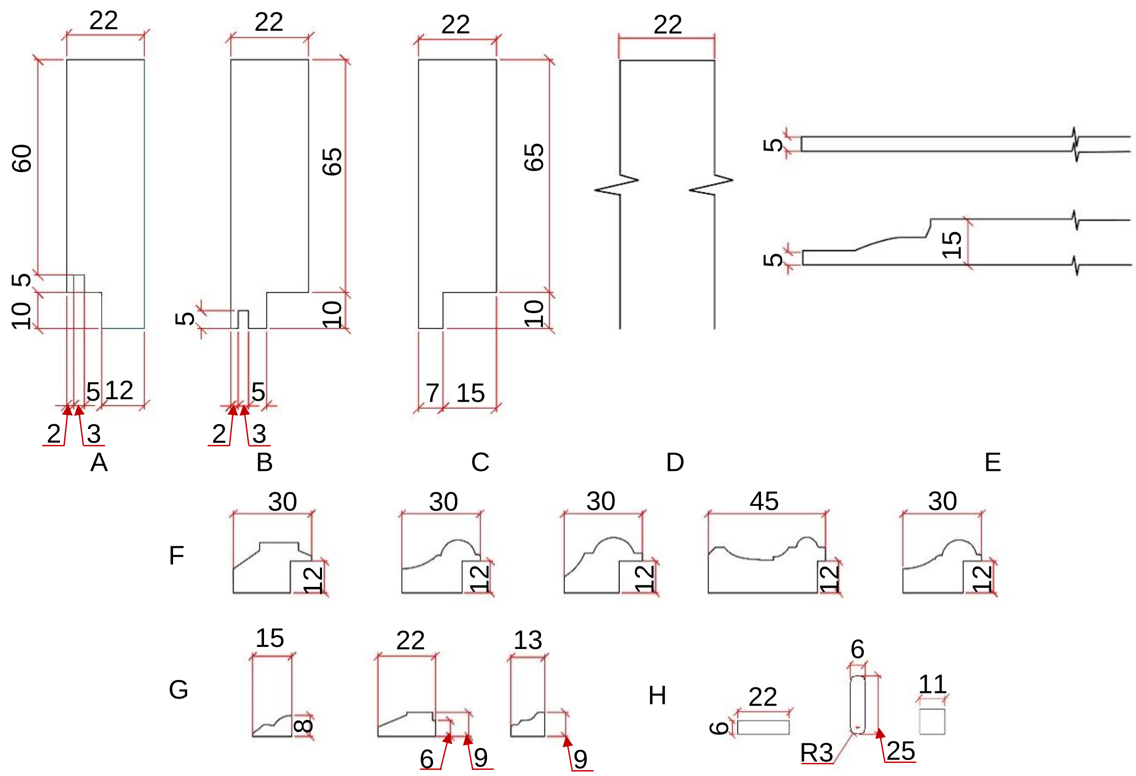

Fig. 11. Parts of the tongue and groove structure

Table 12. Clustering Results of the Tongue and Groove Structure

Category Code	Part Name	Description
A	Four frames CYS0 (05/05F/06/06F/07/07F/08/08F/12/12F/ 13/13F/15/21/21F/28/28F/40/52/54/58/62/63/64)	Frame structure unconnected with wood line
B	Four frames CYS0(45/48/61)	Frame structure connected with pressing line
C	Four frames CYS0 (04/24/24F/29/29F/43/44/46/49/53/59)	Frame structure connected with stuck line
D	Whole panel CYS0 (60/68/67/51)	Whole panel structure
E	All core boards	Structure of core board
F	Wood line CYS0 (45/48/61)	Structure of pressing line
G	Wood line CYS0 (04/24/24F/29/29F/43/44/46/49/53/59)	Structure of stuck line
H	CYS015 (wood louvers and louver frame lines), and CYS052 grid line	The material structure does not unify

Single Index Clustering- Bending Degree

There is a bending shape in the upper frame of some door types, which only has one side of the upper frame and needs special processing by the tenoning machine. After the four frames of some door types are assembled, there is still a corner radian shape. Therefore, the bending radius and corner radian radius of the bending upper frame are counted. When the shape remains roughly the same, the similar sizes are combined. Because there is only one corner radian radius in this paper, it is retained. The relative details are shown in Table 13.

Table 13. Integration of the Bending Degree of the Bending Parts

Door Type	Part Name	Bending Radius (mm)	Corner Radian Radius (mm)	After Merging the Bending Radius (mm)
CYS005F	Upper frame	570	0	570
CYS006F	Upper frame	287	0	350
CYS007F	Upper frame	569	0	570
CYS008F	Upper frame	570	0	570
CYS0012	Upper and lower frame	570	0	570
CYS012F	Upper and lower frame	570	0	570
CYS0021	Four frames	0	20	0
CYS021F	Upper frame	377	20	350
CYS024F	Upper frame	350	0	350
CYS029F	Upper frame	350	0	350

According to the bending radius, the parts with bending shape are classified into three categories, *i.e.* A, B, and C, and the straight materials are uniformly classified into category D, as presented in Table 14.

Table 14. Clustering of the Bending Degree

Category Code	Part Name	Description
A	Upper frame CYS0 (05F/07F/08F), upper and lower frame CYS0（012/012F）	Materials with a bending radius of 570 mm
B	Upper frame CYS0 (06F/024F/029F)	Materials with a bending radius of 350 mm
C	Four frames (CYS021), and upper frames (CYS021F)	Materials with a corner radius of 20 mm
D	Other parts	Straight materials

Part Family Division

By overlapping the synthesis sorting of category codes in Tables 7, 9, 10, and 12 and removing empty sets, 17-part families were obtained in this test, as presented in Table 15. The clustering results show that MOCT is suitable for the division of solid wood door parts family because it can achieve clear clustering results and interpret the meaning of part family from various aspects, *e.g.* AAAA (wide and long material, taking conventional four frames craft route, frame structure unconnected with the wood line, bending radius of 570 mm). The clustering results are sorted according to the importance of attributes and any attribute or multi-attribute overlapping clustering could be selected to meet the needs of different production conditions such as slotting (four side molder). The clustering results of the tongue and groove structure attributes and the corresponding tongue and groove cutter could be selected. If the bending degree only affects the processing mode of the tenoning machine, such an index could be removed and the number of family changes from 17 to 13 when the parts are processed by this process.

Table 15. Clustering Results of the Part Family

Serial Number	Part Family	Part Name
1	AAAA	Upper frame CYS0 (05F/07F/08F/12/12F), and lower frame CYS0(12/12F)
2	AAAB	Upper frame CYS006F
3	AAAC	Four frames and middle frame CYS021, and upper frame CYS021F
4	AAAD	Four frames CYS0 (05/06/07/08/13/13F/15/28/28F/40/52/54/58/62/63/64), left and right frames CYS0 (05F/06F/07F/08F/12/12F/21F) lower frame CYS0 (05F/06F/07F/08F/21F), and middle frame CYS012
5	AABD	Four frames CYS0 (45/48/61）
6	AACB	Upper frame CYS0 (24F/29F)
7	AACD	Four frames CYS0 (04/24/29/43/44/46/49/53/59), left and right frames CYS0 (24F/29F), lower frame CYS0 (24F/29F), and middle frame CYS0 (46/59)
8	ABGD	Wood line CYS0 (04/24/24F)
9	ACGD	Wood line CYS0 (29/29F/59)
10	ADDD	Whole panel CYS051
11	BBFD	Wood line CYS0 (045/48/61)
12	BBGD	Wood line CYS0 (43/44/46/49)
13	BCGD	Wood line CYS0 (40/53)
14	BEHD	Wood louvers and louver frame lines CYS015
15	CEDD	Whole panel CYS0 (60/67/68), composite panel door and log flat panel door
16	CEED	All core boards
17	DCHD	Grid line CYS052

CONCLUSIONS

1. To improve the difficult situation of solid wood cabinet door design and disassembly, a digital design platform is proposed that includes cabinet door data extraction and integration, part family division, coding technology, model base construction, and information interaction and connection. Taking M Company’s 93 cabinet doors as examples, this paper expounded on the key technical principles and practices to lay a foundation for the establishment of a digital design platform for intelligent manufacturing.
2. Part family division method is designed based on MOCT. Select four main attributes that affect the production division, *i.e.* size, craft, tongue, and groove structure, and bending degree to carry on the multiple attribute clustering. Over 40 type cabinet doors of M Company were selected, and 314 solid wood parts were divided into 17-part families. Given the clustering complexity of solid wood parts, this method achieved a good clustering effect and adjustment that could be extensively applied to the group processing of solid wood parts.
3. The number of selected attribute indexes and that of single attribute categories directly affect the division of part families. The more attributes there are, the more detailed the clustering will be. Therefore, it is necessary to control the number of part families reasonably when organizing into group processing. The clustering attributes of solid wood furniture are over the four indexes described in the present study. For different solid wood furniture products, they should be carefully selected according to the needs of their manufacturing sections. This will be of reference significance to the multi-attribute clustering of solid wood furniture.

ACKNOWLEDGMENTS

The authors are grateful for the support of the Technology Innovation Alliance of Wood/Bamboo Industry (Grant No. TIAWBI202010), the Post graduate Education Reform Project of Jiangsu Province (Grant No. SJCX20_0267), and the National Key R&D Program of China (Grant No. 2018YFD0600304).

REFERENCES CITED

Amaral, A., and Peças, P. (2021). "SMEs and Industry 4.0: Two case studies of digitalization for a smoother integration," *Computers in Industry* 125, article no. 103333. DOI: 10.1016/j.compind.2020.103333

Chen, N. (2020). "Ganzhou furniture industry in-depth promotion of solid wood furniture intelligent manufacturing research," *South China Forestry Science* 48(5), 74-78. DOI: 10.16259/j.cnki.36-1342/s.2020.05.017

Dianita, O., Djorgie, T., and Herliansyah, M. K. (2020). "Improvement of production layout in the furniture industry in Indonesia with the concept of group technology," *Advanced Computational Methods for Knowledge Engineering* 1121, 304-310. DOI: 10.1007/978-3-030-38364-0_27

Du, L., Peng, J., Hou J., and Liu, J. (2020). "Clustering-based modularization method and application in aero-engine research and development," *Science Technology and Engineering* 20(18), 7283-7287.

D'urso, P., and Massari, R. (2019). "Fuzzy clustering of mixed data," *Information Sciences* 505, 513-534. DOI: 10.1016/j.ins.2019.07.100

Fang, Y., Xu, W., and Zhan, X. (2020). "Innovation and development of furniture tenon and tenon structure," *Forestry Machinery and Woodworking Equipment* 48(3), 10-12. DOI: 10.13279/j.cnki.fmwe.2020.0024

Gong, Y., Xu, H.-y., Tao, T., and Feng, W.-f. (2019). "Research and application of the part coding for wooden cabinet custom furniture," *China Forest Products Industry* 46(5), 59-61, 64. DOI:10.19531/j.issn1001-5299.201905013

Guo, W. J., Xiong, X. Q., Tang, Y. M., and Pang, X. R. (2018). "Study on large quantity of information interactive technology for customized wardrobe production based on 2020 software," *Journal of Forestry Engineering* 3(2),153-158. DOI: 10.13360/j.issn.2096-1359.2018.02.025

Güven, İ., and Şimsir, F. (2021). "Machine-part formation for cellular manufacturing in group technology: An application for furniture company," *Sakarya University Journal of Science* 25(2), 466-483. DOI:10.16984/saufenbilder.842423

Hao, J. T., Zhao, J. J., and Li, M. L. (2010). "Spatial continuity incorporated multi-attribute fuzzy clustering algorithm for blood vessels segmentation," *Science China Information Sciences* 53(4), 752-759. DOI: 10.1007/s11432-010-0072-2

Hu, W., and Guan, H. (2020). "The application of finite element method in the structure design of solid wood tenon-joint furniture," *World Forestry Research* 33(5), 65-69. DOI: 10.13348/j.cnki.sjlyyj.2020.0034.y

Huang, Z., and Xu, W. (2019). "Analysis and improvement of large format solid wood panels," *Forestry Machinery and Woodworking Equipment* 47(10), 51-53. DOI: 10.13279/j.cnki.fmwe.2019.0119

Hui, X., Wu, Z., and Liu, Z. (2020). "Study of the integration process solutions of solid wood customized furniture based on TopSolid software," *Furniture* 41(3), 65-69. DOI: 10.16610/j.cnki.jiaju.2020.03.015

Jia, Y., Li, J., and Ding, Y. (2016). "Classification and manufacturing technology of customized kitchen cabinet parts based on fuzzy clustering algorithm," *Journal of Forestry Engineering* 1(3), 133-138. DOI: 10.13360/j.issn.2096-1359.2016.03.024

Kulak, O., Sahin, Y., and Taner, M. E. (2012). "Joint order batching and picker routing in single and multiple-cross-aisle warehouses using cluster-based tabu search algorithms," *Flexible Services and Manufacturing Journal* 24(1), 52-80. DOI: 10.1007/s10696-011-9101-8

Li, R., Xu, W., Xiong, X., and Wu, Z. (2018). "Research on the application status of industrial robots in the furniture industry," *Forestry Machinery and Woodworking Equipment* 46(12), 32-35. DOI: 10.3969/j.issn.2095-2953.2018.12.004

Liu, X., and Shi, Y. (2017). "Theory and application of MOCT," *Science and Technology Management Research* 37(2), 222-227.

Liu, Y., Wu, Z., and Xu, W. (2019). "Application of life cycle assessment in furniture industry," *World Forestry Research* 32(2), 56-60. DOI: 10.13348/j.cnki.sjlyyj.2019.0016.y

Liu, G., Ji, H., Ji, W., and Xie, Z. (2020). "Research on part family construction method based on clustering algorithm and BP network," *New Technology and New Process* 42(3), 56-60. DOI: 10.16635/j.cnki.1003-5311.2020.03.014

Liu, Z., Wang, L., Li, X., and Pang, S. (2021a). "A multi-attribute personalized recommendation method for manufacturing service composition with combining collaborative filtering and genetic algorithm," *Journal of Manufacturing Systems* 58(A), 348-364. DOI: 10.1016/j.jmsy.2020.12.019

Liu, J., Chen, L., and Liu, R. (2021b). "Research on multi-center intelligent manufacturing sharing cloud platform for furniture manufacturing enterprises," *Journal of Forest Engineering* 6(3), 166-170. DOI: 10.13360/j.iSSN.2096-1359.202003031

Lv, J., Wang, Z., Pan, W.J., Zhao, H.L., and Liu, Z.H. (2019). "Research on the modular division method of customized products based on hierarchical clustering," *Modular Machine Tool and Automatic Manufacturing Technology* 61(11), 134-138. DOI: 10.13462/j.cnki.mmtamt.2019.11.034

Ma, J. (2017). "Multi-attribute utility theory based k-means clustering applications," *International Journal of Data Warehousing and Mining* 13(2), 1-12. DOI: 10.4018/IJDWM.2017040101

Ma, Z., Wu, Z., and Shen, Z. (2020). "Research on production scheduling plan of solid wood customized furniture enterprises based on ERP+MES platform," *China Forest Products Industry* 57(8), 53-57. DOI: 10.19531/j.issn1001-5299.202008012

Pang, N., Zhang, J., Zhang, C., Qin, X., and Cai, J. (2019). "PUMA: Parallel subspace clustering of categorical data using multi-attribute weights," *Expert Systems with Applications* 126, 233-245. DOI: 10.1016/j.eswa.2019.02.030

Ren, J., Xiong, X., Zhao, J., Fei, J., and Zhang, J. (2022a). "The standardization of real wood custom cupboard door design," *Journal of Forestry Engineering* 7(1), 197-204. DOI: 10.13360/j.issn.2096-1359.202103018

Ren J., Xiong, X., Tang, Y., Zhao J., Fei J., Zhang J. (2022b). "Furniture part family division of customized wooded cabinet doors using multi-attribute cross clustering," *Journal of Forestry Engineering* 7(3), 187-193. DOI: 10.13360 /j.issn.2096-1359.202107019

Rijati, N., Sumpeno, S., and Purnomo, M. H. (2018). "Multi-attribute clustering of student's entrepreneurial potential mapping based on its characteristics and the affecting factors: Preliminary study on Indonesian higher education database," in: *Proceedings of the 2018 10th International Conference on Computer and Automation Engineering*, Brisbane, Australia, pp. 11-16.

Song, H., Yi, S., Liu, M., Qin, G., and Zheng, W. (2016). "Research on the classification of parts into groups based on processing resources," *Journal of Shanghai Jiaotong University* 50(9), 1460-1466. DOI: 10.16183/j.cnki.jsjtu.2016.09.018

Tang, T., Teng, L., Wu, J., and Chen, M. (2018). "Comprehensive realization of digitization is the only way to intelligent manufacturing – Interpretation of intelligent manufacturing road: Digital factory," *China Mechanical Engineering* 29(3), 366-377.

Tao, T., Wang, J., Liu, Z., Chen, X., and Feng, W. (2020). "Clustering analysis of panel custom furniture orders based on ant colony clustering algorithm," *Forest Products Industry* 57(5), 49-52. DOI: 10.19531/j.issn1001-5299.202005011

Wei, Z., Xie, X., and Lv, W. (2020). "Self-adaption vessel traffic behaviour recognition algorithm based on multi-attribute trajectory characteristics," *Ocean Engineering* 198, 106995. DOI: 10.1016/j.oceaneng.2020.106995

Wiedenbeck, J., and Parsons, J. (2010). "Digital technology use by companies in the furniture, cabinet, architectural millwork, and related industries," *Forest Products Journal* 60(1), 78-85. DOI: 10.13073/0015-7473-60.1.78

Wu, Z. (2019). "Typical process and equipment of mechanical ingredients in the production of solid wood furniture," *Furniture* 40(4), 1-5. DOI: 10.16610/j.cnki.jiaju.2019.04.001

Xiao, Y., Yang, X., Cui, G., Xia, Q., Zhou, K., Zhang, F., and Xia, Y. (2021). "Module partition method for complex mechanical products based on spectral clustering algorithm," *Journal of Light Industry* 36(1), 73-81. DOI: 10.12187/2021.01.010

Xiong, X., Yuan, Y., Pan, Y., and Wu, W. (2020). "Automatic identification and intelligent sorting technology of customized household based on kneading single production," *Chinese Journal of Forestry Engineering* 5(6), 162-167. DOI: 10.13360/j.iSSN.2096-1359.201911005

Xiong, X., Lu, G., and Lu, D. (2021). "Research on children's customized furniture design based on group technology," *Applied Sciences* 11(23), 11371. DOI: 10.3390/app112311371

Xiong, X., and Yue, X. (2022). "Research and application progress of China's home furnishing intelligent manufacturing technology," *Journal of Forestry Engineering* 7(2), 26-34. DOI: 10.13360/j.issn.2096-1359.202107006

Yang, Y., Liu, W., and Li, G. (2019). "A probe into the brain cognition of users' different preferences for furniture products," *Journal of Forestry Engineering* 4(5), 152-158. DOI: 10.13360/j.issn.2096-1359.2019.05.022

Yang, X., and Xiong, X. (2022). "Information collection and application of furniture production line using radio frequency identification technology," *Journal of Forestry Engineering* 7(3),180-186. DOI: 10.13360 /j.issn.2096-1359.202109023

Zhang, F., Wu, Z., Ding, J., Guo, X., Cao, P., and Zhu, Z. (2021). "Milling performance of stone-plastic composite with diamond cutters," *Materialwissenschaft und Werkstofftechnik* 52(12), 1307-1318. DOI: 10.1002/mawe.202100215

Zhou, Z., and Zang, Z. (2020). "Research on furniture design application based on parametric technology," *Forest Products Industry* 57(4), 33-37. DOI: 10.19531/j.issn1001-5299.202004007

Zolfani, S. H., Maknoon, R., and Zavadskas, E. K. (2016). "Multiple attribute decision making (MADM) based scenarios," *International Journal of Strategic Property Management* 20(1), 101-111. DOI: 10.3846/1648715X.2015.1132487
Zhu, Z., Jin, D., Wu, Z., Xu, W., Yu, Y., Guo, X., and Wang, X. A. (2022a). "Assessment of surface roughness in milling of beech using a response surface methodology and an adaptive network-based fuzzy inference system," *Machines* 10(7), 567. DOI: 10.3390/machines10070567
Zhu, Z., Buck, D., Wu, Z., Wang, J., Guo, X., and Zhu, M. (2022b). "Built-up edge formation mechanisms in orthogonal cutting of wood-plastic composite," *Wood Material Science & Engineering*, 1-9. DOI: 10.1080/17480272.2022.2086064
Wu, Z., Buck, D., Jin, D., Guo, X., Cao, P., and Zhu, Z. (2022). "Investigation on milling quality of stone-plastic composite using response surface methodology," *JOM* 74(5), 2063-2070. DOI: 10.1007/s11837-021-05024-y

Article submitted: May 13, 2022; Peer review completed: June 25, 2022; Revised version received and accepted: July 27, 2022; Published: July 29, 2022.
DOI: 10.15376/biores.17.3.5393-5419