

# FLUX 2.0: Sustainable Furniture Production with Modular 3D Printed Joinery System

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**Abstract.** The Malaysian furniture industry confronts a complex landscape defined by conventional wood joinery practices, resulting in rising material wastage, labour-intensive procedures, and intricate logistical challenges. This research explores designers' perceptions regarding sustainable furniture production and the feasibility of integrating modular 3D-printed joinery within an ergo-aesthetic framework. Data was collected through a survey (n = 424) in Malaysia. The analysis revealed significant correlations for senses and external influence ( $r = 0.325$ ,  $p < 0.05$ ), strong external influence with design attributes ( $r = 0.549$ ,  $p < 0.05$ ), and substantive design attributes with external influence connection ( $r = 0.580$ ,  $p < 0.05$ ). Ergonomic components highlight the correlations between physical with cognitive ( $r = 0.525$ ,  $p < 0.05$ ), cognitive with organisational ( $r = 0.547$ ,  $p < 0.05$ ), and organisational with physical ( $r = 0.546$ ,  $p < 0.05$ ). Incorporating physical ergonomics, comfort, usability, and user interaction, alongside cultural considerations, provides opportunities to improve functionality and user satisfaction in prototypes. By understanding designers' perspectives on sustainable furniture production and assessing modular 3D printed joinery, the study explains the relationship between design elements, sensory factors, aesthetics, and sustainable practices.

## 1 Introduction

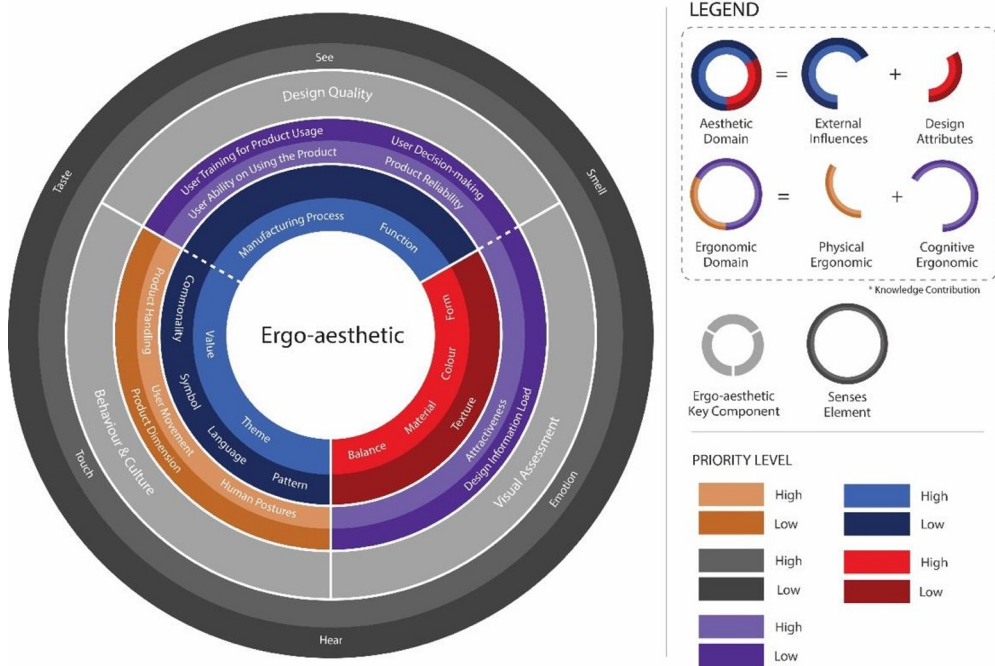
The Malaysian furniture business is vital to the nation's economy, significantly boosting employment and export earnings. However, traditional wood joinery fabrication methods pose significant challenges, limiting the industry's potential for growth and sustainability. Manufacturing poses a significant threat to the environment during production and significantly impacts the growing challenges associated with product end-of-life concerns. Manufacturers are accountable for meeting society's rising expectations and wants [1]. This paper aims to shed light on the Malaysian furniture industry's pressing issues and proposes innovative solutions to address these challenges. The Malaysian furniture industry's challenges include high material waste, labour-intensive organic shape design, and

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difficulties in handling and storage for transportation. Traditional construction techniques often result in substantial material waste due to the complexity and inefficiency of the fabrication processes. Excessive waste not only depletes valuable resources but also contributes to environmental degradation.

Moreover, designing and manufacturing furniture with organic shapes requires skilled craftsmanship, leading to high labour intensity. This labour-intensive process hampers productivity and increases production costs, making it difficult for manufacturers to compete in the global market. Addressing these challenges is crucial for the industry's long-term sustainability and competitiveness. The high production and transportation costs affect manufacturers' profitability and contribute to the generation of substantial furniture waste. Thus, there is a need for innovative solutions that promote cost-effective and sustainable manufacturing methods in the Malaysian furniture industry.



**Fig. 1.** The Ergo-Aesthetic framework.

Quality and design are the most essential purchase decision factors [2–4]. The concept of ergo-aesthetic (Figure 1) reveals the harmonic fusion of form, shape, and symbolism with human behavioural traits in furniture design. It emphasises the crucial balance between furniture's functional and ergonomic aspects and the aesthetic considerations that evoke emotional and sensory responses in users. By incorporating ergonomics and aesthetics into the design process, the ergo-aesthetic approach ensures that furniture meets users' physical needs and comfort and engages them emotionally and cognitively. This equilibrium between human behaviour and design elements enables the creation of furniture that not only serves its practical purpose but also communicates meaning, resonates with users, and enriches their overall experience. The concept of ergo-aesthetic thus highlights the transformative power of design, where furniture becomes a medium for enhancing well-being, fostering emotional connections, and enriching human lives [5].

Industrial designers play a crucial part in the cycle of consumer culture by making new technology pleasant to be owned [6]. Users reported more positive perceptions when the

visuals were aesthetically pleasing, well-maintained and visually harmonious [7,8]. Industrial designers should embrace advanced manufacturing technologies, such as computer numerical control (CNC) machines and robotic systems. Adopting sustainable materials can considerably reduce reliance on conventional timber resources and offset environmental effects. Examples include engineered wood products and recycled materials. Additionally, using flat-pack packaging and modular designs can maximise transportation effectiveness by requiring less space and lowering the danger of damage in transit.

## 2 Methods

### 2.1 Sample selection

A purposive sampling technique was employed to ensure that the selected participants were industrial designers and design professionals with a minimum diploma qualification in design-related fields. This approach ensures that the respondents possess the necessary expertise and understanding of design principles because specific target population segments were intentionally overrepresented in the sample.

### 2.2 Data collection

A structured questionnaire was designed to address the research objective parallel to the recommendation of ISO 9001 in the design and development process [9] and the development process of furniture design [10]. The questionnaire contained three sections: research for consumer needs, planning for design and development, and preparing a design brief tailored to explore designers' perceptions of sustainable furniture production and their evaluation of the feasibility of modular 3D-printed joinery. The questionnaire was distributed to the selected sample of 424 respondents.

### 2.3 Statistical procedures for data analysis

IBM SPSS Statistics version 25.0 was used to conduct the statistical analysis. To gauge the degree of association between distinct variables concerning designers' perceptions of sustainable furniture production and the viability of integrating modular 3D printed joinery within an ergo-aesthetic framework, the Pearson Correlation was employed.

For the first research objective, the Pearson Correlation coefficient was utilised to ascertain a significant relationship between designers' perceptions of sustainable furniture production and variables such as their experience level, educational background, or prior exposure to sustainable design practices. A positive correlation could indicate that heightened experience or education corresponds with more favourable attitudes towards sustainable practices. In addressing the second research objective, the Pearson Correlation coefficient was utilised to evaluate the connection between ergonomic factors, including comfort and usability, and aesthetic considerations concerning the feasibility of modular 3D printed joinery. This analytical approach aimed to discern whether a substantial correlation exists between ergonomic satisfaction and aesthetic preferences, particularly in contemplating the adoption of this innovative joinery technique.

A significance level of 95% was applied to determine the statistical significance of the identified correlations, ensuring a robust assessment of relationships between variables. This comprehensive analysis seeks to illuminate the intricate interplay of factors shaping designers' perspectives and preferences, offering valuable insights into sustainable design practices and innovative manufacturing methodologies.

### 3 Results and discussion

The results of the Pearson correlation analysis for research for consumers' needs, planning for design and development, and preparing design briefs are presented below. The correlations are reported for both aesthetic and ergonomic variables.

**Table 1.** Association between design activities with aesthetic and ergonomic components

Design Activities	Aesthetic			Ergonomic		
	Senses	External Influence	Design Attributes	Physical	Cognitive	Organisational
Research for consumer needs	.325	.532	.580	.525	.547	.546
Planning for design and development	.316	.549	.582	.583	.595	.569
Preparing design brief	.330	.552	.521	.492	.552	.516

For consumers' needs in terms of aesthetic variables, a moderate positive correlation was observed between senses and external influence ( $r = 0.325$ ,  $p < 0.05$ ), as well as between external influence and design attributes ( $r = 0.532$ ,  $p < 0.05$ ). A stronger positive correlation was found between design attributes and external influence ( $r = 0.580$ ,  $p < 0.05$ ). Regarding ergonomic variables for consumers' needs, significant positive correlations were identified between physical and cognitive aspects ( $r = 0.525$ ,  $p < 0.05$ ), as well as between cognitive and organisational factors ( $r = 0.547$ ,  $p < 0.05$ ). Furthermore, a significant positive correlation was observed between organisational and physical variables ( $r = 0.546$ ,  $p < 0.05$ ).

In the context of planning for design and development, for aesthetic variables, a moderate positive correlation was evident between senses and external influence ( $r = 0.316$ ,  $p < 0.05$ ), as well as between external influence and design attributes ( $r = 0.549$ ,  $p < 0.05$ ). Moreover, a stronger positive correlation was found between design attributes and external influence ( $r = 0.582$ ,  $p < 0.05$ ). For ergonomic variables in planning, a significant positive correlation was observed between physical and cognitive factors ( $r = 0.583$ ,  $p < 0.05$ ). Additionally, a strong positive correlation was identified between cognitive and organisational variables ( $r = 0.595$ ,  $p < 0.05$ ), as well as between organisational and physical factors ( $r = 0.569$ ,  $p < 0.05$ ).

For the preparation of design briefs concerning aesthetic variables, a moderate positive correlation was found between senses and external influence ( $r = 0.330$ ,  $p < 0.05$ ), as well as between external influence and design attributes ( $r = 0.552$ ,  $p < 0.05$ ). Furthermore, a significant positive correlation was observed between design attributes and external influence ( $r = 0.521$ ,  $p < 0.05$ ). In the realm of ergonomic variables for preparing design briefs, significant positive correlations were identified between physical and cognitive factors ( $r = 0.492$ ,  $p < 0.05$ ), as well as between cognitive and organisational aspects ( $r = 0.552$ ,  $p < 0.05$ ). A significant positive correlation was also observed between organisational and physical variables ( $r = 0.516$ ,  $p < 0.05$ ).

The correlations observed among cognitive ergonomics, organisational ergonomics, design attributes, physical ergonomics, external influence, and the stages of the design process hold significant implications for developing the FLUX 2.0 prototype (Figure 2). These relationships offer valuable insights that guide designers in prioritising and

incorporating essential elements into the prototype to enhance its ergonomics and aesthetics. The notable correlations, varying from moderate to strong, between cognitive ergonomics, organisational ergonomics, design attributes, and the stages of the design process highlight the pivotal role of these factors in shaping the overall design experience by representing a more streamlined model that is made to untangle the hideous flow to achieve the intended output [11]. These findings underscore the importance of considering these ergo-aesthetic elements in developing the FLUX 2.0 prototype to ensure alignment with user experience and design objectives. A good designer should always identify, understand and react towards the specific technical and aesthetic aspects throughout the design process flow [12].



**Fig. 2.** The joinery system of the FLUX prototype

Similarly, the observed moderate correlations between physical ergonomics, external influence, and the design process stages suggest the relevance of these factors in prototype development. By encompassing physical ergonomics, comfort, usability, and user interaction, along with accounting for external influences such as cultural and societal factors, the FLUX 2.0 prototype can be tailored to enhance functionality, user satisfaction, and cultural resonance. Conversely, the relatively weak associations between the senses and the design process stages imply that taste and smell may hold less priority within the context of the FLUX 2.0 prototype. However, other sensory dimensions like sight, touch, and sound remain significant and warrant careful consideration during prototype development, ensuring a comprehensive and engaging user experience.

To effectively address the identified challenges, implementing the ergo-aesthetic framework in developing FLUX 2.0 involved creating a full-scale proposed design. This design ingeniously tackled the identified issues by seamlessly integrating ergonomic and aesthetic considerations. The proposed design's comprehensive application of the ergo-aesthetic framework ensured a harmonious blend of ergonomic functionality and visual allure, resulting in an appealing and user-centric final prototype. The FLUX 2.0 project's implementation of the full-scale planned design successfully exemplifies how the ergo-aesthetic framework is used effectively. It emphasises the importance of incorporating ergonomic and aesthetic considerations when creating cutting-edge, user-centred designs that jive with functionality and aesthetic appeal.

## 4 Conclusion

In conclusion, this research explores the relationships between sustainability, innovation, and design senses. The study aimed to understand designers' perspectives on sustainable furniture production and to evaluate the practicality of a modular 3D printed joinery system within an ergo-aesthetic framework. The study emphasises how designers respond to trends and incorporate design elements and sensory factors, highlighting the intricate balance between aesthetics and sustainable practices. The strong correlations among ergonomic dimensions also emphasise the multifaceted aspects essential for achieving ergonomic excellence.

Overall, these research findings may become the basis for a future where the harmonious alignment of sustainability, technological progress, and design craftsmanship influences the direction of furniture production methods.

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