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A Case Study in Natural Fibre Material (Luffa Sponge) Development Using E^2-Material-Driven Design

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Abstract: To unleash the emotional potential of natural fibre materials in sustainable development and utilisation, this paper presents a material-driven design method with emotional and ecological indicators (E^2-MDD). The method offers product-level solutions for the sustainable development of natural materials. The method involves several steps, such as screening the main material quality, capturing the user emotion vision, deconstructing the E^2 vision pattern, and deducting the product design concept. The method was tested on luffa sponge samples, seen as one kind of traditional fibre resource, which resulted in four differentiated schemes, which were evaluated using the E^2-MDD ring radar column score chart. The study identified three key emotional qualities for natural fibre materials: associativity, uniqueness, and biophilicity. The results show that product concepts closer to the natural material's original form scored higher, while the inclusion of non-natural materials had a negative impact on the evaluations. This study also found that E^2-MDD could strengthen the emotional and ecological connection between people and products, further indicating that material and design can establish a link between environmental friendliness and emotional experience. Lastly, the paper suggests future development areas for the E^2-MDD method, including focusing on users, ecology, and business.

Keywords: sustainable material design; user emotions; Luffa sponge-based materials; material-driven design; E^2-MDD

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1. Introduction

As awareness for environmental protection continuously strengthens, sustainable design has gradually permeated every aspect of today's societal production and lifestyle. Recently, the escalation of ecological issues has garnered widespread attention in material science towards developing natural materials, renewable materials, and biodegradable materials [1–5]. Among these, fibre materials, including natural fibre and natural fibre composites, are extensively applied across various critical development sectors of multiple industries [6–10]. Due to their inherent environmental friendliness [11] and material affordance [12], they can be easily integrated into societal life. However, some applications are relatively direct, such as using luffa sponge as household cleaning tools. Furthermore, natural fibres offer new opportunities after initial processing through their thermal conductivity, dyeability, and mould resistance [13], contributing to sustainable design.

Although current scientific and technological means can assist designers in quickly and comprehensively understanding materials, focusing too narrowly on the materials themselves may overlook the interaction and emotional experience between the material and users, thus failing to establish connections to materials [14]. Moreover, traditional material design in China often involves artisans designing and producing products intending to leverage material properties or inherit intangible cultural heritage, rather than creating from the perspective of the emotions and experiences materials evoke in people.

Therefore, we sought to find the relation between natural fibre, ecology, and emotion, adding consideration for designers and users. In the following, we will discuss two categories: materials and methods of exploring materials.

1.1. Materials

This paper focuses on exploring natural fibre materials in emotional sustainability design, taking locally traditional materials as the subject of study. When these materials are widely utilised in product design, their history can assist designers in imbuing them with relevant meanings [15], enabling products to better respond to users' emotional needs [16]. Luffa sponge specifically, which is derived from the fruit of the luffa sponge plant, is a bio-based material with commercial value and environmental friendliness, characterised by its recyclability [17] and biodegradability [18]. The chemical composition and physical structure of luffa sponge exhibits excellent characteristics, especially a fibrous network structure of vascular bundles, with its random distribution offering significant advantages [19]. Consequently, luffa sponge holds great potential in applications such as adsorbents, cell immobilisation media, and composite materials [20].

Approximately 90% of the absorption capacity of fibre materials comes from the accessible voids between or on the fibres [21], including but not limited to adsorption, energy absorption, and water absorption. Firstly, materials with high specific surface areas and high proportions of mesopores can store or capture green resources [20,22]. Secondly, the interconnected three-dimensional structure inside luffa sponge, along with its external morphological characteristics, endows it with directionality. When used laterally and longitudinally, the buffering characteristics of polyester sponges and corrugated cardboard are shown, respectively [23]. Coupled with good mechanical stress and exhibiting "shape memory" phenomena [24], it is widely used in fillings for pillows, shoulder pads, etc. [25]. Lastly, the natural porous characteristics of luffa sponge impart it with both hydrophilic and oleophilic properties [26]. Most existing luffa sponge products are in their natural colour; hence, changing the colour through dyeing them can create more possibilities. Further, they can be combined with other materials. In addition, the open three-dimensional mesh of luffa sponge possesses accommodating and supporting characteristics, plus it is low cost, non-toxic, biodegradable, and convenient to use [27], making it highly suitable for cell immobilisation and activity [28].

1.2. Material-Driven Design (MDD)

Numerous scholars have proposed various theories and tools to explore the relationship between material development and emotional design [29]. In particular, the material-driven design (MDD) proposed by Elvin Karana and others can be divided into four steps [30]. It significantly stimulates designers' sensitivity and creativity towards materials; however, exploring the limitations and potential of MDD has led to identifying two critical areas with potential for further development. Firstly, the unique attributes of natural materials prompt reflective behaviour. MDD is frequently employed to develop and explore relatively unknown and exploratory materials [12,31]. MDD advocates are redefining common materials with new meanings in novel domains [30], with most practices being initiated with an intuitive sensory approach. Projects like "Stitch" [32], designed by Taner Olcay and colleagues within game interaction, aim to explore the correlation between material experiences and engaging interactivity. Fibre materials, influenced by natural elements, evolve into diverse fibre monomers. This process leverages visual, olfactory, and tactile experiences—qualities directly perceivable by humans—to explore new possibilities in materials, colours, and designs, resulting in products that carry a sense of life and resonate more effectively with the audience [33].

Second is the emotional experiences evoked by products made from natural materials. Grounded in functional applicability, MDD supports designers in perceiving innovation through experience. Though MDD delves into the emotional characterisation of materials, the approach is predominantly function-oriented, such as Alejandro Plumed and others' exploration of eco-friendly materials in the industrial sector [34]. Furthermore, a significant trend has been observed where products are discarded not because of a lack of physical durability but rather due to a loss of attachment by the users [35]. Products that evoke enjoyment or foster connections with people, places, and events have strengthened users' "attachment" to them [36]. This emotional bond is not only a potential motivator for consumers to engage in sustainable behaviours but also a crucial consideration in sustainable design [37]. In short, the emotions conveyed by a product are triggered by the materials, the way it is designed, and the interaction between people and the environment [38]. In turn, the sustainability of a product is related to the materials and design approach [39,40]. Thus, materials and design establish a link between ecology and emotion.

1.3. User Emotions and Product Eco Assessment

Addressing these concerns, enhancing the MDD framework includes sustainable ecological design evaluation factors and emotional considerations. Initially, in the steps of experiencing and understanding materials, this paper selects the systematic toolkit Ma2E4, developed by the Material Experience Lab at the Delft University of Technology, for the empirical characterisation of materials [41], aiming to achieve a comprehensive material experience, enrich designers' vocabulary, and spark emotions and actions [42].

Furthermore, ecological design is considered from a whole-lifecycle perspective in establishing standards for material experience models, particularly for one of the sustainable design phases. This approach comprehensively evaluates and optimises the environmental impact throughout the product's life cycle. This study, adhering to the core principle of MDD where the user is the designer, selects the designer's eco analysis [43] to evaluate the environmental friendliness of natural fibres during the design and production phases, aiming to produce, use, recycle, and dispose of products in as natural a manner as possible [44]. This allows for targeted process interventions, thereby proposing systemic solution capabilities.

Lastly, for another dimension of product concept evaluation—consideration of emotional factors—emotional design strengthens the emotional connection between people and objects, enhancing the attachment relationship between users and products [45]. However, self-reporting, although the most reliable and detailed method for measuring user emotions, does not effectively convey emotions through the users' intuitive language [46]. Therefore, to ensure that users' emotional needs are translated into useful design information, we choose the Product Emotion Measurement tool (PrEmo) [47,48]. It is a non-verbal emotional measurement tool that enables participants to accurately describe their emotions, as shown in Figure 1 [47].

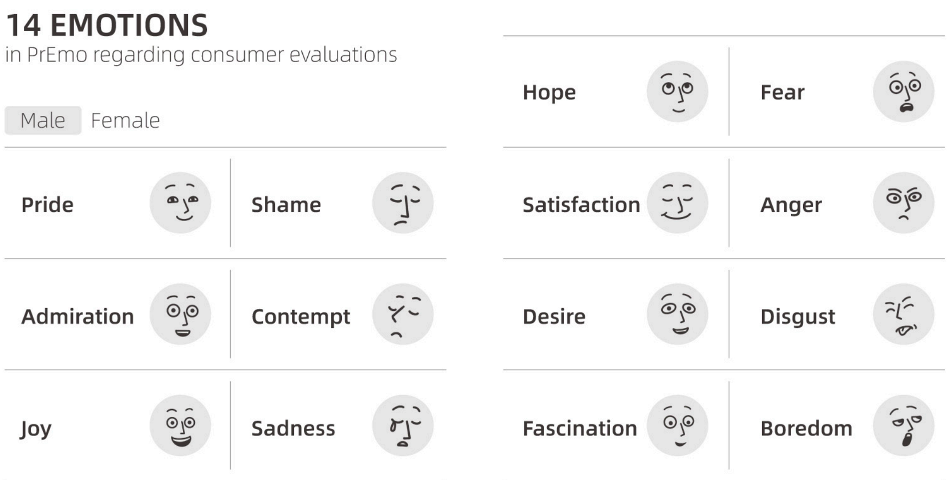

Figure 1. Graphic references to 14 emotions in PrEmo regarding consumer evaluations [47].

1.4. Aims of the Study

The variation in this design process from traditional MDD lies in its adoption of a more streamlined process aiming to explore traditional materials with local characteristics and thus enhancing the final product output through ecological design evaluation and emotional measurement methods. This approach offers new insights into the project, detailing the method's steps to a more detailed and applied level. Although luffa sponge is the material chosen for this study, both the MDD and emotional design principles have universality. It is hoped that this work will offer new design perspectives for showcasing the value and exploring the experiences of other traditional materials.

2. Materials and Methods

2.1. Theory

As previously mentioned, the exploration of materials by designers and material scientists needs to find a balance; industrial designers must devote time and energy to understanding scientific knowledge and actively participate in experiments to promote successful interdisciplinary collaboration in materials science [49]. However, they should not overly focus on one aspect to the extent that they lose sight of innovation in material user experience or emotional design. Additionally, when experiencing a product, users react not only to the product itself but also to its associated connotations. The components of these connotations [50], similar to the dimensions explored in material experiential characterisation [51], include emotional traits, further demonstrating the richness and depth of material metaphors. Therefore, to better develop natural and regional materials from a designer's perspective against the backdrop of sustainable development, and to excavate and amplify traits that have received less attention, it is necessary to assess and validate their feasibility in a scientifically rational manner. Beyond the specific operations suggested by the material-driven design approach, we will endow it with more details from a new perspective, starting from the angles of emotional design and ecological adaptability. This redefines the design model, aiding designers in exploring materials more rationally from the user's perspective, and provides a specific evaluation path within this model.

The method is named E^2-MDD, where E^2 stands for the dual focus on emotion and ecology. This represents an enhanced exploration of MDD for regional natural materials, aiming to discover and validate the ecological sustainability and emotional narrative characteristics of materials. This method is based on the adaptive cycle proposed by Holling and colleagues [52]. Unlike the original use of a four-phase cycle to describe the evolving dynamics of systems, E^2-MDD employs a four-phase cycle to outline the application process and sustainable effects of the method, specifically, screening the main material quality, capturing the user emotion vision, deconstructing the E^2 vision pattern, and deducting the product design concept. This entire cyclical system is built around the three fundamental elements of materials, users, and designers. The horizontal and vertical axes represent the dominant factors of the designer and the user's emotions, respectively, with the distance from the origin indicating the relative weight of these factors. The process of developing and utilising materials spans this entire space, with the material as the focal point, as illustrated in Figure 2. This is a process where the dominance of user emotions gradually increases as the design process advances (phase 1 to phase 2). Upon reaching the vision deconstruction step, both the designer's involvement and the user's emotional participation are condensed, highlighting the objectivity shaped by emotional measurement and ecological assessment at this stage. As the process continues, the proportions of the two axis factors are rapidly released, with both designers and users peaking in the concept output stage (phase 3 to phase 4), after which the cycle can either restart or conclude with the results. Natural materials, as the main subject of the process, achieve a dynamic balance and cycle between four stages and two dimensions.

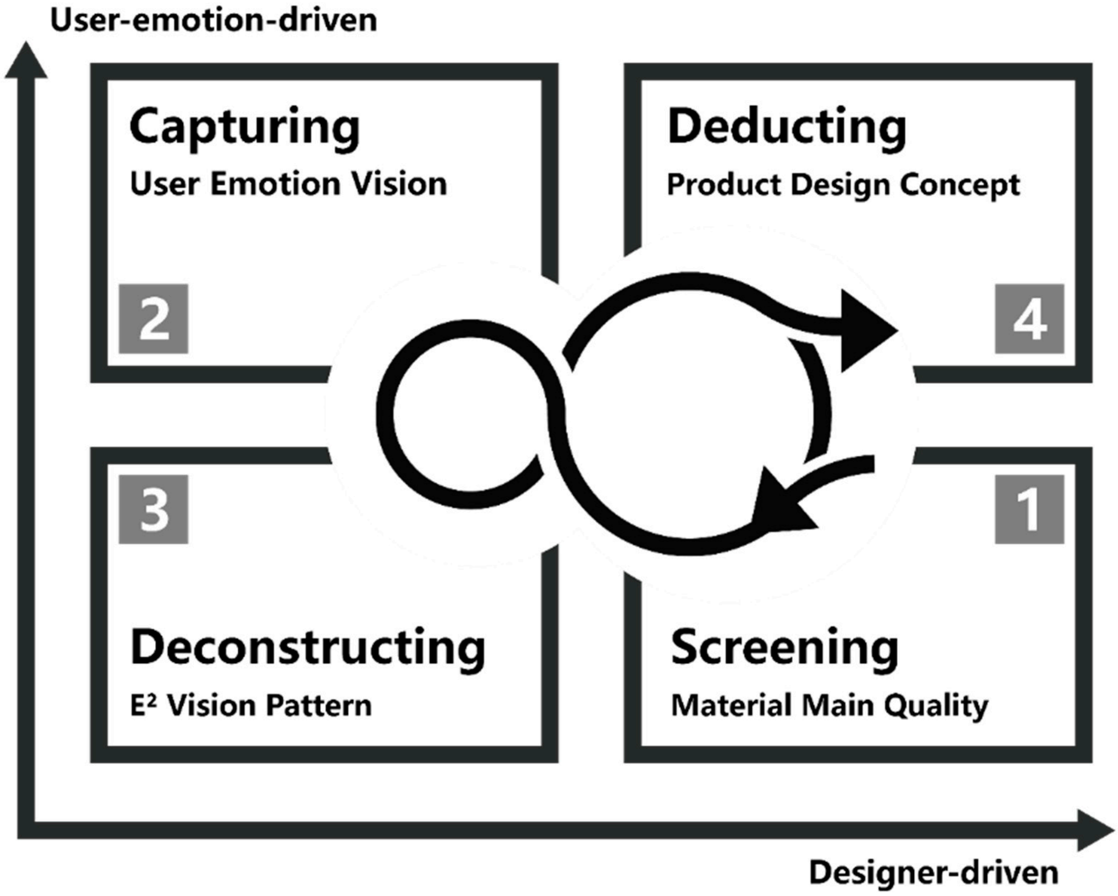

Figure 2. E^2-MDD four-step cycle system.

2.1.1. Screening Main Material Quality

Screening the main material quality denotes the initial engagement of designers with region-specific natural materials. Initially, it is imperative for designers to acquire a comprehensive understanding of the material at hand, which encompasses but is not limited to three principal research methodologies. The first approach involves accessing relevant performance characteristics through existing resources, such as online material databases. The second approach entails conducting interviews with material scientists and other pertinent technical personnel to perform on-site or tangible examinations of the material. The third approach involves engaging in hands-on experimental testing, including cutting, grinding, dehydrating, and mixing, to characterise the material technically. Integrating these approaches facilitates a holistic understanding of natural materials, whether developed, semi-developed, or undeveloped, thereby unveiling opportunities for their application within products. The essence of this phase is to identify and amplify a specific physical characteristic of the natural material, followed by technical differentiation and categorisation, leading to the creation of material experience samples for application in subsequent phases. Notably, this physical characteristic often bears relevance to the material's historical applications. Regional materials are distinguished by their recognisability and direct usability in traditional applications, with individuals typically gravitating towards the most intuitive and easy-to-use characteristics. The enduring applicability of these characteristics over time not only underscores their representativeness but also embodies the emotions bestowed by nature and accumulated over time within these characteristics.

2.1.2. Capturing User Emotion Vision

Capturing the user emotion vision involves exploring the experiential characterization of the material and creating related experience visions. Designers employ the Ma2E4 tool (MEL, Delft, The Netherlands), starting from the four experiential dimensions of performative level, sensorial level, affective level, and interpretive level, to experience the series of samples based on the main physical characteristics of the material obtained from the first step. The process includes but is not limited to questionnaire surveys, focus groups, and semi-structured interviews. User behaviour experiences towards the material samples, sensory feedback, and more are documented. Any emotional experience elicited by the material samples can assist designers in understanding the material's sensory quality, emotional significance, and regional connotation, as well as the interrelationships among these elements.

After users have completed their experiences with the material samples, designers use qualitative research methods to summarise and deduce the results, presenting both unique and common characteristics based on samples of the same material in different forms. The uniqueness is distilled for innovative control in product concept creation, while commonalities conclude the material's experience vision, thereby defining the user–product interaction. By integrating commonly existing experience patterns, several clear intentions of people related to the material and even a broader context are extracted. The significance of this step lies in summarising material characteristics, reflecting on material applications, and applying the output results to subsequent vision deconstruction.

2.1.3. Deconstructing E^2 Vision Pattern

Deconstructing the E^2 vision pattern involves establishing assessment methods and dimensions that can evoke the targeted significance. The materials targeted by E^2-MDD typically originate from nature, and this approach aims to unearth the intrinsic emotional characteristics of the materials. Therefore, in the third step, the PrEmo measurement method will serve as the guiding approach, supplemented by the Likert scale, to qualitatively and quantitatively assess the intensity of given emotions. To discover the significance of the material as a regional natural substance, this step also incorporates the ecological design analysis in the designer's eco analysis. Finally, by integrating some of the experiential qualities summarised from step two and combining them with the emotional and ecological dimensions, the importance of emotion and ecology in the assessment is highlighted. This showcases that the method is guided by these two dimensions and internalises the dimensions derived from user experience, thereby generating a new model for evaluating the concepts produced in the following step.

The circular radar bar chart, as shown in Figure 3, is divided into four sections, organised from the outer to the inner layers as follows: the occurrence frequency of the fourteen expressions measured by the PrEmo method (red line) and the total scores (yellow line), the average scores of the six dimensions of ecological design analysis, the average scores of the three dimensions derived from capturing users' emotional visions in the second step, and the product concept expression chart. The outer ring is divided into fourteen equal parts, recognising that a limited range of emotions might not suffice to express the multitude of emotions elicited by an object [53]. After experiencing the product concept, users can use the PrEmo method to select at least one emotion characteristic that represents their first intuition, and then choose the intensity level according to the strength of the emotion. Progressing inward, the following layers represent the six dimensions of ecological design analysis and the three perceptual attributes related to materials and products, which the designer distils from the experiential qualities identified in the second step. Both sets of attributes are scored within their respective circular spaces using a five-point Likert scale, providing a broader perspective on the interconnection strength between various dimensions.

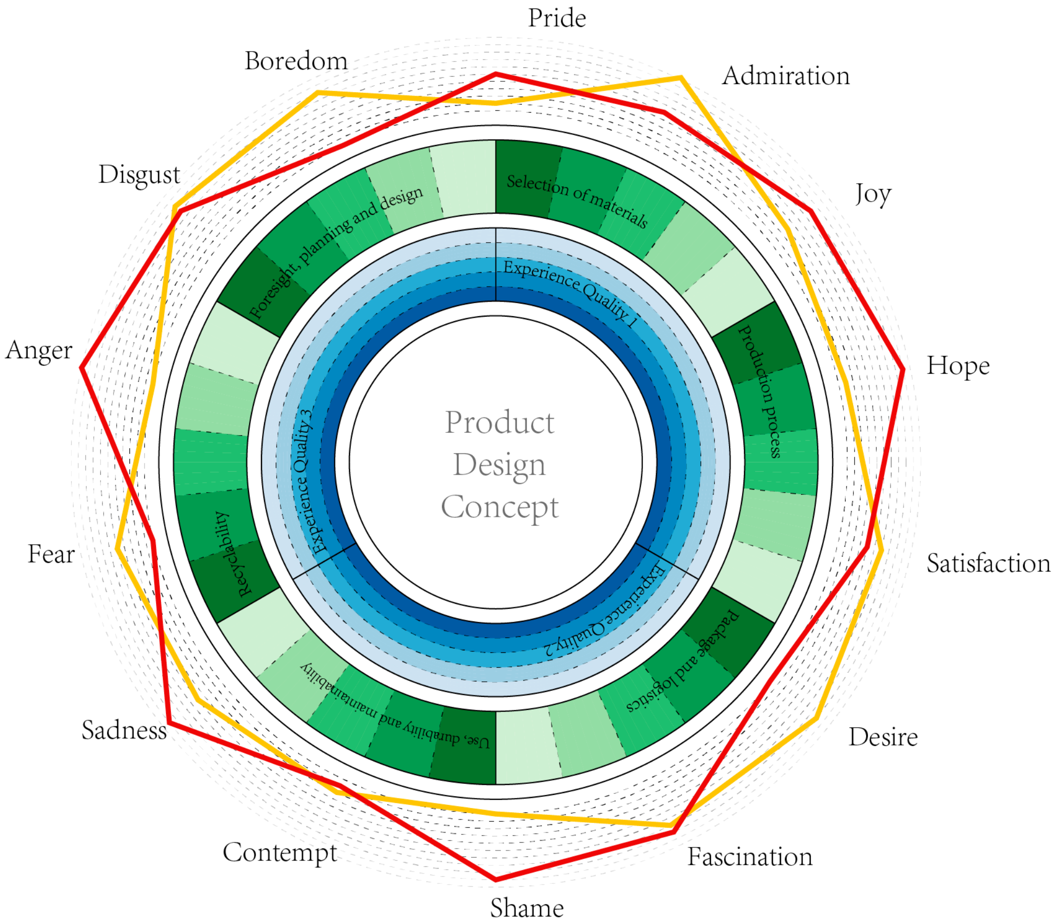

Figure 3. E^2-MDD ring radar column score chart (blue shade represents the score of three experience qualities, green shade represents the score of the six dimensions of ecological design analysis, yellow line represents the score of different emotions in PrEmo, red line represents the occurrence frequency of emotions in the PrEmo).

2.1.4. Deducting Product Design Concept

Deducting the product design concept involves integrating the findings above into the product concept design stage. Starting from both the designer's and the user's perspectives, after selecting and magnifying the material's technical characteristics, exploring user experience representations, and deconstructing the emotional vision in the preparatory phase, designers should already have some ideas for the product concept. Initiating from one or multiple points, with natural materials as the core of the design, the final outcome should be a series of product concepts that aligns with the material experience vision.

Subsequently, combining the results from step three, designers will re-invite users to evaluate the product design concepts. The ideal outcome is product concepts that score highly overall and lead in the emotional and ecological dimensions, while those with significant fluctuations in their curves require comparative discussion. If subsequent product evaluations are less than satisfactory, the process may return to step one for a new design cycle. The journey from excavating the characteristics of materials to generating material-driven products, and from material to product and back to material, embodies the sustainable cycle of regional natural materials. Investigating whether the unique properties of regional natural materials can trigger specific emotional experiences, further exploring these emotions and applying them to products and then validating these applications, represents the essence of the E^2-MDD method.

2.2. Procedure

Figure 4 is an experimental flowchart that compares the design methodology with the validation experiments, and this logic will be followed next in practice. All findings and design configurations were documented.

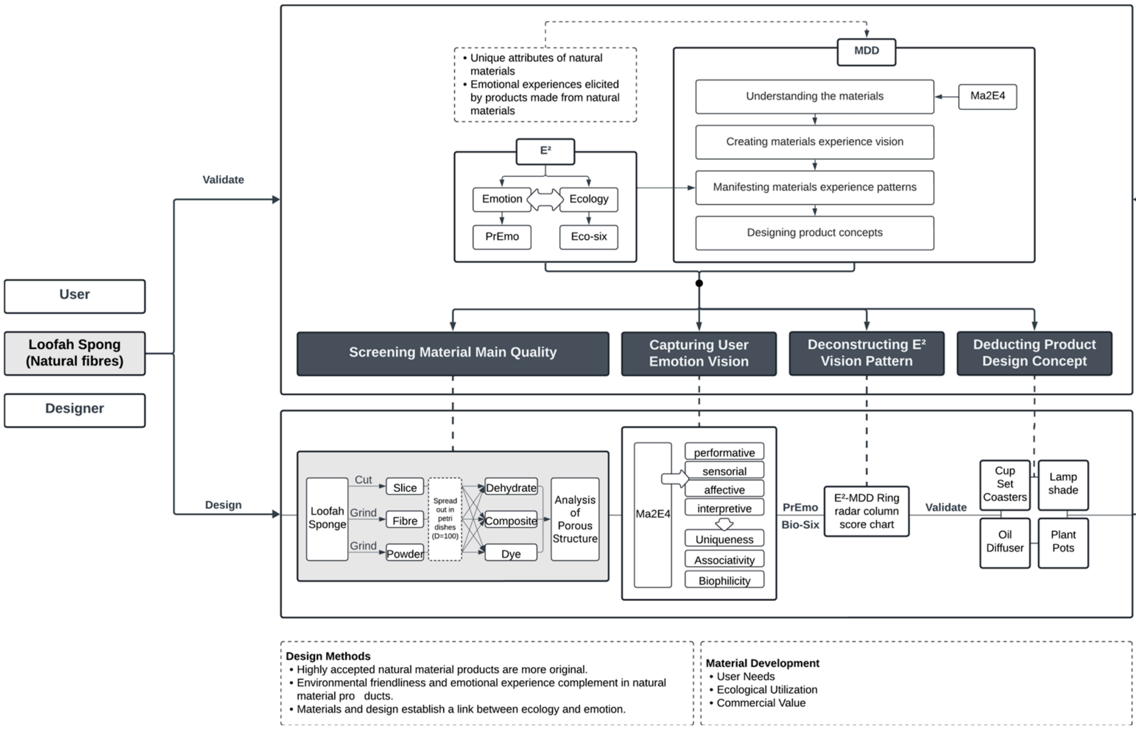

Figure 4. Experimental flowchart.

2.3. Practice

To validate the feasibility of E^2-MDD in exploring regional natural materials and to delve into the design trends of such materials under the guidance of emotion and ecology, the study utilised luffa sponge as the primary material in the following steps.

2.3.1. Screening Main Material Quality

In the preliminary phase, the research team reviewed a substantial amount of literature on luffa sponge to form an initial understanding of this material. Subsequently, through interviews with professionals in materials science and observation of a physical luffa sponge, the team enhanced their understanding of the material. During the technical characterisation of the material, the team first processed luffa sponge into powder, fibre, and slice forms using cutting, grinding, and other processing methods. Next, samples of the three different forms were spread out in transparent Petri dishes with a diameter of 100 mm, with sliced materials being cut into circular pieces measuring 10 * 10 cm. Finally, the three different form samples in the Petri dishes were subjected to dehydrate, dye, and composite tests to further characterise the various features of the luffa sponge, as shown in Figure 5, and a comparison of the experimental samples is shown in Figure 6. Comparative analysis of the experimental samples revealed that the material processed into fibre form not only exhibited good plasticity but also retained the luffa sponge's network-like porous structure, representing a physical form with derivative space.

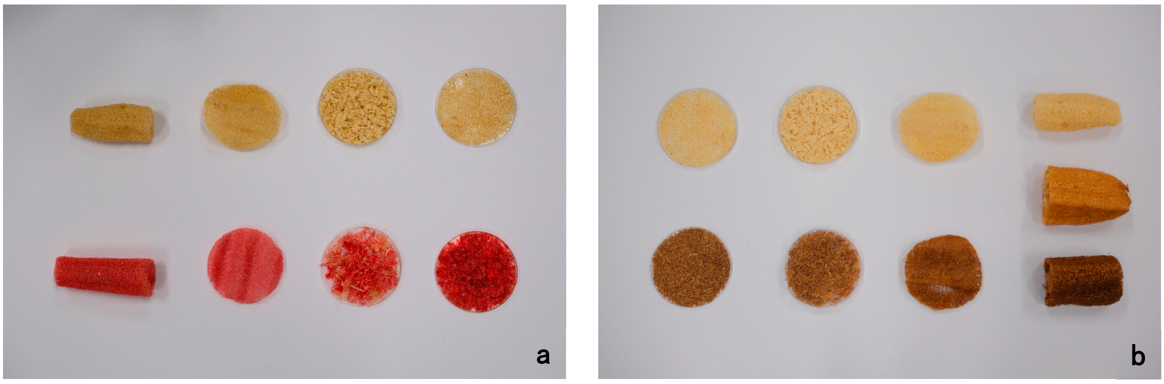

Figure 5. Original and treated luffa sponge with different morphologies: (**a**) dyed; (**b**) dehydrated.

Figure 6. Samples obtained by combining three different forms of luffa sponge (slice, fibre, powder) with four treatments (original, dehydrated, dyed, composite).

2.3.2. Capturing User Emotion Vision

In this phase, the research team recruited 11 students with a design background, aged between 23 and 25 years, who were unfamiliar with the material. They were guided to use the Ma2E4 tool to experience the material samples (powder, fibre, slice) from the behavioural, sensory, emotional, and interpretive dimensions and to reflect upon their experiences. During the detailed questionnaire and interview process, their behaviours and feedback were documented, as shown in Figure 7. Finally, Ma2E4 data analysis for three samples of luffa sponge fibre is shown in Figure 8.

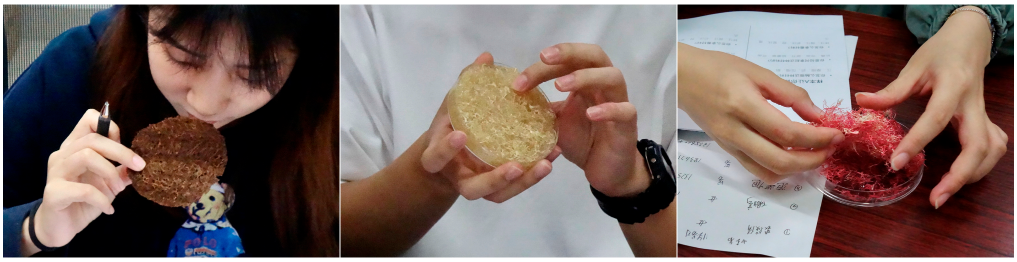

Figure 7. Experimental process record (smell, poke, pinch).

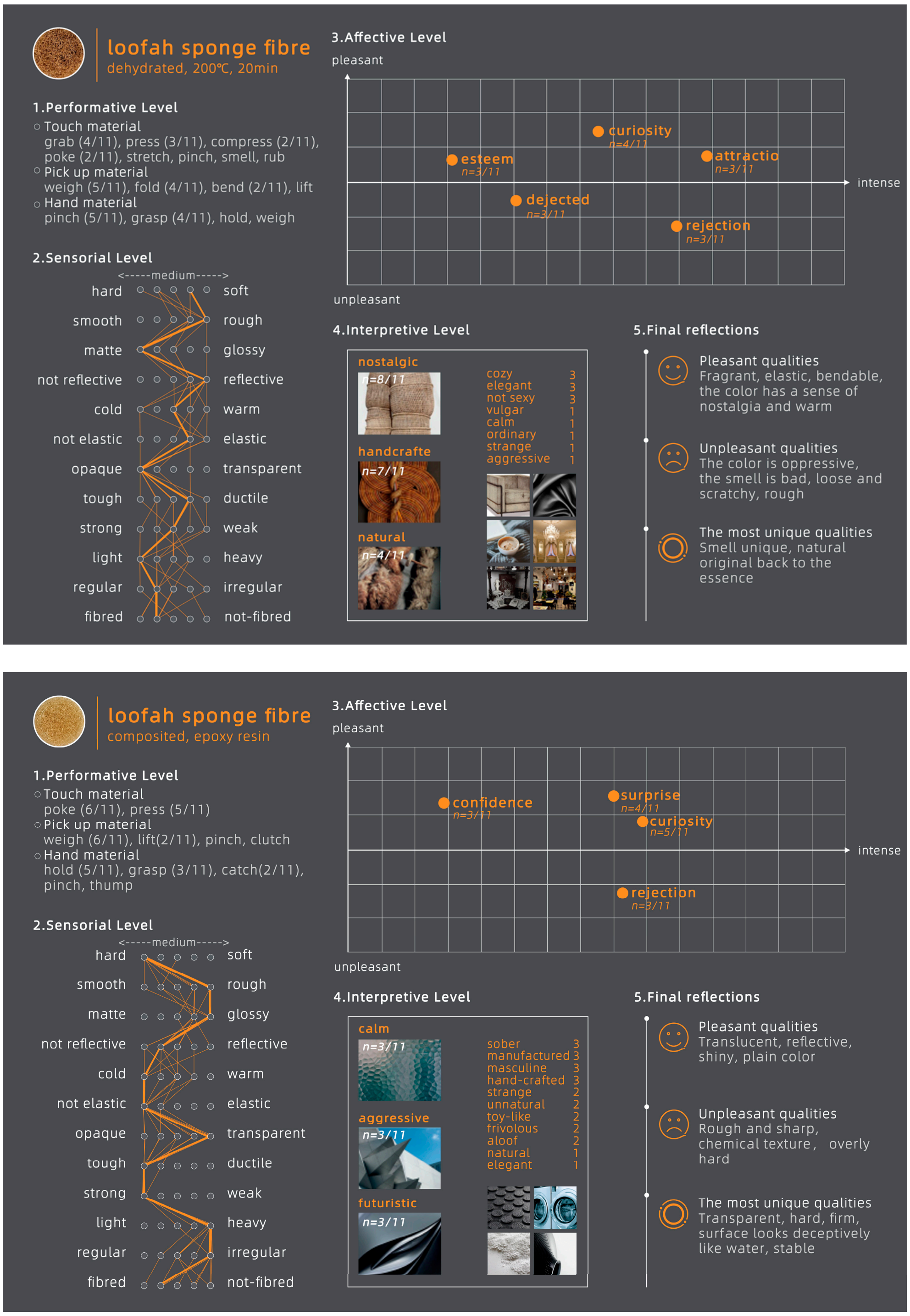

Figure 8. *Cont.*

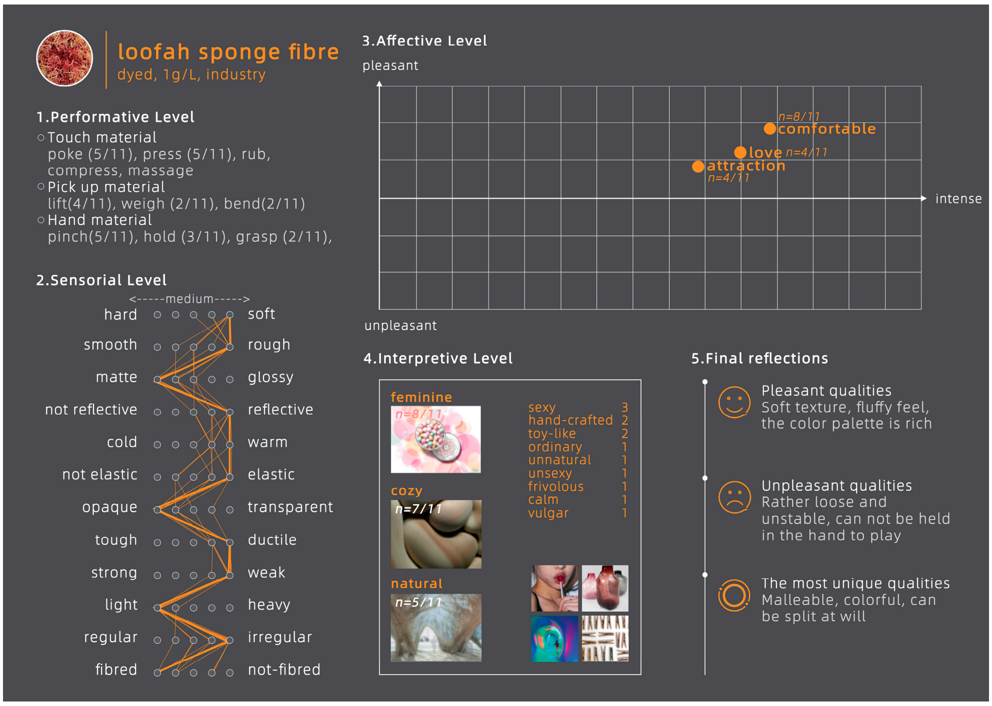

Figure 8. Ma2E4 data analysis for three samples of luffa sponge fibre.

On the behavioural level, students engaged with the materials, with recurring actions including smelling, poking, pressing, and so on. Sensory-wise, the three samples exhibited extremes in the "smooth–rough," "matte–glossy," "opaque–transparent," and "light–heavy" dimensions. Emotionally, positive evaluations such as attraction, curiosity, comfort, love, esteem, surprise, and confidence were observed, along with negative emotions like rejection and dejection, providing support for a comprehensive understanding of the pleasure the luffa sponge samples brought to users. Interpretively, the samples inspired different associations, with the most frequent intentions being (A) nostalgic, hand-crafted, natural; (B) calm, aggressive, futuristic; and (C) feminine, cosy, natural. After the interpretive level, final reflections were sought from the participants by asking three questions: "What is the most pleasant quality of the material?," " What is the most unpleasant quality of the material?," and " What is the most unique quality of the material?," resulting in a variety of personal statements, such as, "The charred colour gives a nostalgic feeling" (A), "a unique smell" (A), "translucent" (B), "relatively hard" (B), "easily separable" (C), "the warmth formed by colour and softness" (C), and more.

In summary, combining findings from previous steps with user experience feedback, a vision statement was formulated: The irregular luffa sponge fibres from either initial processing or no processing bring about visual, olfactory, and tactile associations, detailed into its naturally unique appearance, primitive smell, and three-dimensional shrinkable porous structure. This makes the luffa sponge a carrier that can create unique effects and drive instinctive user reactions with its original form or simple processing. Thus, designing a product based on luffa sponge utilises its physical properties in harmony with the product's use or user interaction to produce an effect greater than the sum of its parts and supports natural disposal. The designer distilled three experience qualities from the vision statement: "associativity" (associations brought on by visual, olfactory, and tactile aspects, and how well they fit with the product), "uniqueness" (the unique aspect of using luffa sponge as the main material in similar products), and "biophilicity" (the degree of liking and the desire to own luffa sponge products). These qualities will be used in the construction of subsequent vision dimensions.

2.3.3. Deconstructing E^2 Vision Pattern

Based on the experiential qualities extracted in the second step, to delve into the material's intrinsic emotional characteristics and ecological sustainability, the designer explored the PrEmo measurement method and the ecological design analysis across six dimensions. With user experience as the focus, the exploration emphasised the relationship between the material's/product's form and its emotional and ecological aspects. To illustrate the results, the design team created a comprehensive radar chart to display the strength of associations among the various dimensions, as shown in Figure 9. The assessment results will be used to inform the selection of product concepts in the next step.

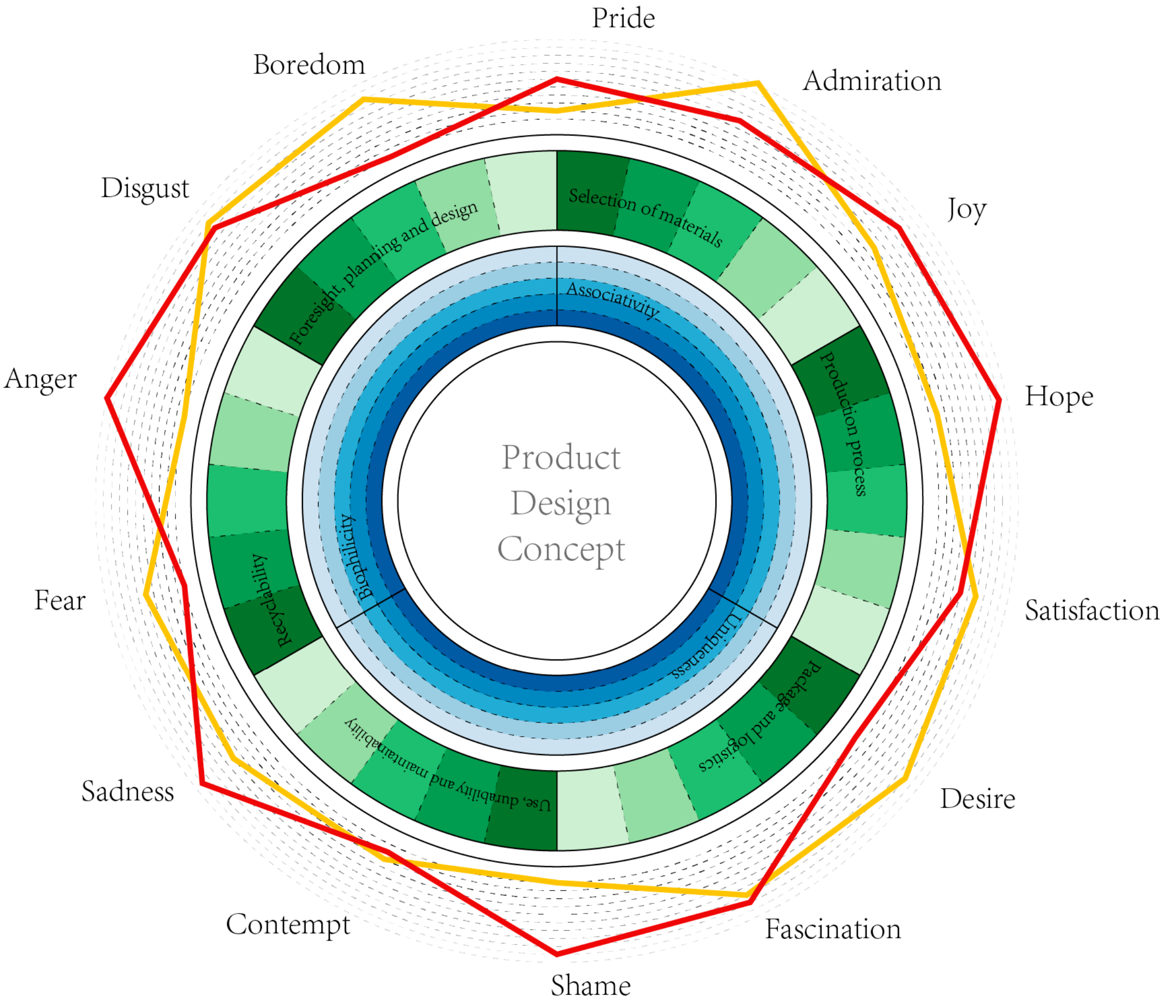

Figure 9. E^2-MDD ring radar column score chart (final version).

2.3.4. Deducting Product Design Concept

In the fourth step, designers began sketching or directly creating product concepts based on luffa sponge, combining the experimental results from the previous steps with brainstorming and multiple iterations to output design concepts that reflect the material's characteristics. Of course, the design team could jump directly to this step from the first step, provided they have sufficient understanding of the material and mature product ideas. Eventually, four concepts were created: a cup sleeve and coaster set, a lampshade, a diffuser, and a flowerpot, as shown in Figure 10. Concept one, the cup sleeve and coaster set, utilises the anisotropic properties and "shape memory" phenomenon of the luffa sponge, highlighting the cushioning properties of its directional mesh pore structure. Concept two, the lampshade, combines transparent epoxy resin to showcase better the loose and translucent properties of luffa sponge fibres. Concept three, the diffuser, utilises the porosity and water absorption of the luffa sponge by dyeing it and adding essential oils, meeting both aesthetic and functional needs. Concept four, the flowerpot, uses the adsorption and porosity of dehydrated and carbonised luffa sponge to create a sustainable, fully biodegradable concept.

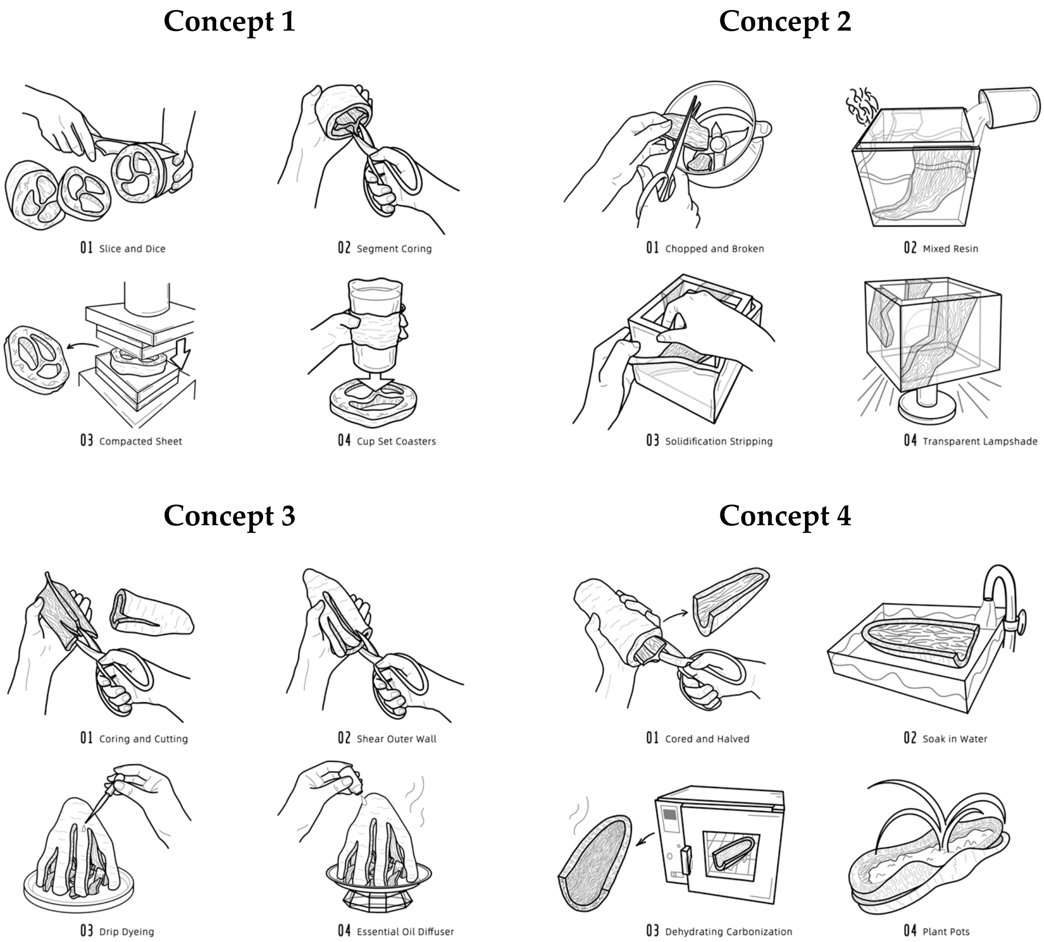

Figure 10. Overview of the four product concepts for luffa sponge-based materials.

Subsequently, users utilised the evaluation system created in the third step (E^2-MDD ring radar column score chart) to analyse the above product concepts, selecting the one that best met the emotional and ecological standards. These four concepts were evaluated by a new group of 11 students with similar backgrounds, aged between 23 and 25 years, as shown in Figure 11a. Before the evaluation, students signed an informed consent form and were briefly introduced to the experiment by the personnel before experiencing the raw material of the luffa sponge. During the evaluation, students could take the luffa sponge samples at any time, as shown in Figure 11b, to assess the products more comprehensively from their perspective through free imagination. The only consideration was to contemplate the uniqueness of luffa sponge as a raw material in similar category products, focusing on the ecological sustainability of the entire process and the emotional impact the product had on them. Figure 11c shows the participants' experience of anisotropy with concept 1, a cup sleeve and coaster set; Figure 11d shows the light transmission experience with concept 2, a lampshade; Figure 11e shows the olfactory experience with concept 3, a diffuser; and Figure 11f shows the internal and external structure experience with concept 4, a flowerpot.

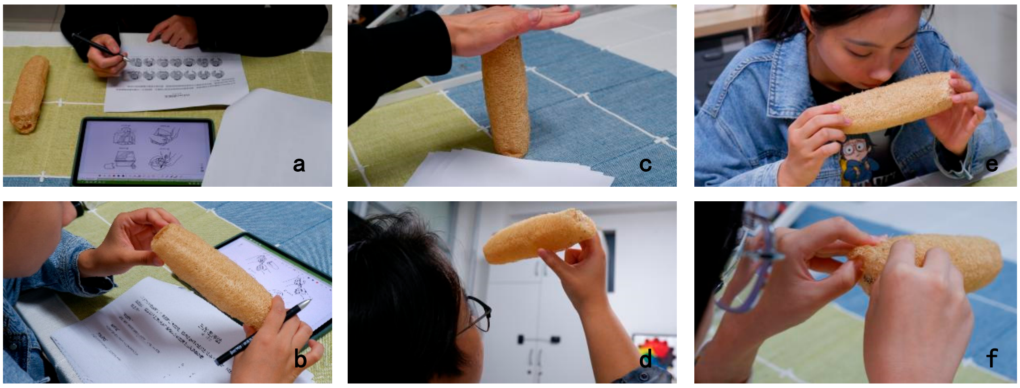

Figure 11. (**a**) Layout of the experimental procedure; (**b**) experiencing in assessment; (**c**) students experiencing anisotropy in concept 1; (**d**) students experiencing transparency in concept 2; (**e**) students experiencing odours in concept 3; (**f**) students experiencing structure in concept 4.

The results consist of three parts, including Table 1 for the average scores of the three experiential qualities in the first link, Table 2 for the average scores of the six dimensions of the ecological design in the second link, and Table 3 for the PrEmo scores (negative emotions were reverse scored). Table 1 reflects the scores of the four concepts under three experiential qualities (associativity, uniqueness, and biophilicity), showing that concept 4 scored the highest overall (11.1818), with concept 2 being the lowest (9.6364). In all subcategories, concepts 3 and 4 scored exceptionally high in uniqueness. Table 2 shows the scores of the four concepts under the six dimensions of ecological design analysis, with concept 1 scoring the highest (3.4848) and concept 2 scoring the lowest (2.7879). Table 3 represents the PrEmo scores of the four concepts, which generally showed a positive attitude, with concept 1 scoring the highest (91) and concepts 2 and 3 the lowest (61).

The results from these three tables and additional data are visualised in bar graphs and radar charts, presented in Figure 12, showing that the concept 1 occupied the largest shaded and polyline area, followed by concept 4. The conclusion is that a concept with a higher overall score and higher scores in the emotional and ecological dimensions (larger shaded area and polyline area) is more likely to be widely adopted.

Table 1. Mean score table for the three qualities of experience.

	Concept			
	1	**2**	**3**	**4**
Associativity	3.2727	3.0000	3.2727	3.5455
Uniqueness	3.1818	3.5455	4.0909	4.0909
Biophilicity	3.7273	3.0909	3.0909	3.5455
Total	10.1818	9.6364	10.4545	11.1818

Table 2. Mean score scale for the six dimensions of ecology.

	Concept			
	1	**2**	**3**	**4**
Foresight, planning, and design	2.7273	2.7273	3.2727	3.6364
Selection of materials	3.4545	3.000	3.2727	3.6364
Production process	3.4545	3.0909	2.6364	3.1818
Package and logistics	3.9091	2.6364	2.6364	2.3636
Use, durability, and maintainability	2.8182	3.0000	3.0000	3.0000
Recyclability	4.5455	2.2727	3.8182	4.0909
Total	3.4848	2.7879	3.1061	3.3182

Table 3. Score table for PrEmo.

	Concept 1	2	3	4
Pride	1	0	0	0
Admiration	13	11	11	14
Joy	22	14	12	23
Hope	19	8	18	10
Satisfaction	6	1	0	3
Desire	13	16	7	20
Fascination	21	25	27	19
Shame	0	4	0	2
Contempt	0	0	1	1
Sadness	0	0	0	0
Fear	3	0	5	4
Anger	0	2	1	1
Disgust	0	1	4	1
Boredom	1	7	3	2
Total	91	61	61	78

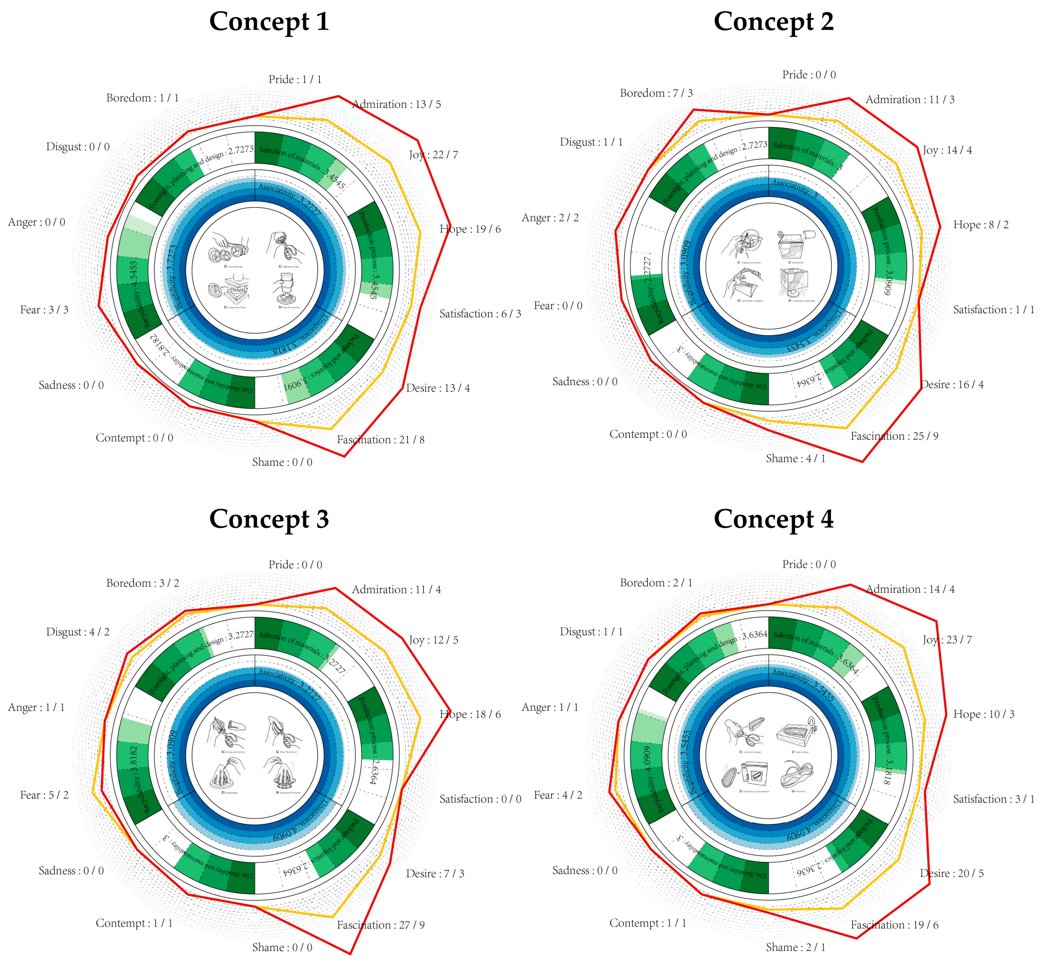

Figure 12. E^2-MDD ring radar column score for the four concepts.

3. Discussion

In this paper, a region-specific traditional material is used to create a product concept with ecological benefits and emotional experience. Building on MDD and supplemented with sub-methods such as PrEmo and designer's eco analysis, we propose the E^2-MDD approach, which aims to explore the specific manifestations of ecological and emotional aspects in product concepts. Compared to MDD, E^2-MDD has advantages in uncovering the emotional characteristics of natural materials and incorporates ecological dimensions. Through steps such as screening the main material quality, capturing the user emotion vision, deconstructing the E^2 vision pattern, and deducting the product design concept, it is demonstrated that the natural material of luffa sponge can enhance the emotional connection between people and objects, eliciting positive emotional resonance from users.

3.1. Reflections on Design Methods

To further elucidate this method, it is imperative to clarify the genesis of this research tool and its intended use. Initially, we derived two extensions from MDD, positing that the unique attributes of natural materials could resonate with and provoke reflection among users. This primarily manifests in the first step of E^2-MDD, where the most representative physical properties of natural materials are selected and magnified after technical characterisation. The second extension stems from the emotional experiences elicited by products made from natural materials. In the third step of E^2-MDD, we incorporated ecological and emotional assessment dimensions, aiming to unearth the intrinsic emotional characteristics of materials and highlight the ecological friendliness of products. Our research supports the notion that materials are active participants in the creation of finished goods or the design process of products [54]. This perspective is not only relevant to the ethos of material-driven design but also holds more profound implications for the control of interaction between designers, material scientists, and users. Designers, compared to material scientists, are more adept at uncovering the emotional semantics of natural materials, creating product concepts that more accurately reflect the interaction and emotional experience between materials and users.

The essence of creation lies in the fusion of proactive discovery and creation [55], necessitating an active engagement with and contemplation of materials to forge unique material forms. In practice, we first seek to understand materials through their differentiated forms. In subsequent evaluations using the E^2-MDD ring radar column score chart and related interviews, user feedback is diverse: questions about whether concept 1's water absorption and thermal insulation meet the target, appreciation for concept 2 for evoking memories of old kerosene lamps despite not being primitive, concerns about whether concept 4 becomes brittle and difficult to transport after carbonisation, remarks on the simplicity of concept 1's production suggesting simple packaging, and overall favourable consideration for purchasing concept 4 . . . Scores displayed in the circular radar bar chart provide a visual representation of the multidimensional paths to specification, as shown in Figure 12. Ultimately, the concept proposals reveal differentiated emotional feedback and ecological evaluations. The overall scores, from highest to lowest, are concept 1, a cup sleeve and coaster set (104.6666); concept 4, a flowerpot (92.5); concept 3, a diffuser (74.5606); and concept 2, a lampshade (73.4243) (Tables 1–3). Through this multidimensional exploration, we unveil the best commercial product concepts for luffa sponge.

This research indicates that product concepts for natural, regional materials that are highly accepted by users tend to be closer to the material's original form. For instance, concept 1, the cup sleeve and coaster set, received the highest score on the E^2-MDD ring radar column score chart. This may be because the most straightforward forms can better reflect the most essential aspects of the material [56]. Using luffa sponge for its cushioning properties in various directions for cup sleeves and coasters is also a direct application of the primal impulse towards the material.

Furthermore, we also discovered that environmental friendliness and emotional experience should complement each other for products made entirely from regional materials. The positive emotional scores for the concept proposals were significantly higher than the negative emotional scores (Table 3), indicating that the ecological advantages of natural materials positively influence user emotions. Additionally, concepts without added materials received higher recognition, especially in the ecological dimension, with concept 2, which incorporated epoxy resin, scoring significantly lower than the other three concepts (Table 2).

Ultimately, materials and design establish a link between ecology and emotion. As Tables 2 and 3 shows, the high and low scores on ecological aspects are basically in line with the high and low scores on the emotional aspects, like the highest score of 3.4848 in Table 2 of concept 1 corresponding to the highest score of 91 in Table 3. Therefore, by developing natural materials through this method, we can strengthen the ecological and emotional connection between people and objects. The ecological dimension aims to have products return entirely to nature once their lifespan is exhausted while also providing users with a heightened emotional experience. Thus, guiding design with materials while retaining humanity's primal impulse towards materials to create products that enhance emotional engagement is also beneficial to the natural environment.

3.2. Application Prospects for Material Development

Following the design process of luffa sponge guided by E^2-MDD, we realise that the effective use of the method requires adjustments based on the material focus and design objectives, which can serve as a starting point for new methods or tools. Based on this case study, we consider how this method could provide value for improvements in subsequent projects or explorations in designing with different materials. We propose the following applications, which could benefit specific domains:

3.2.1. User Needs

Emotion can be embedded into material design to enhance user need capture. Our exploration of natural material design confirms that everything from material development to strengthening the connection between users and products is closely related to emotion, such as the users receiving emotional feedback from the two material experiences, as evidenced by the sensorial level in Ma2E4 and the scores shown in PrEmo. Given the diversity of materials, limiting ourselves to natural materials alone may not be wise. We anticipate creating new materials inspired by nature, a powerful method for developing new materials or structures [57], as well as composite and innovative materials with various forms and applications that could significantly alter the experience of future interactive products [5,58]. This suggests that under the premise of technological advancement, it is necessary to find the correct expression of emotion in the design process to explore sustainable design and pursue user emotions.

3.2.2. Ecological Utilisation

The advantages of natural regional materials should be rediscovered to expand application scenarios. Nature harbours countless complex and intricate structures [59], and the design of natural materials in this method involves deconstructing its characteristics and simplifying complexity. Exploring the properties and comparative analysis of a natural fibre like luffa sponge reveals its essence as a fibre with a three-dimensional porous structure. Related physical properties include adsorption, directionality, translucency, etc., allowing for the design of product concepts for various application scenarios. Over the past decade, the interaction between design and biology has increased and solidified within biomimetic design methodologies [60]. In short, simple, practical, and eco-friendly concepts can embody metaphorical expression and aesthetic value in research work, aligning with sustainable design principles and potentially contributing further to the harmony between humans and nature [61].

3.2.3. Commercial Value

Designers need to integrate users' emotional factors into the design process to increase the purchase rate. Designers and users participating together in the entire design process have their emotions interact with the product. There is a significant positive correlation between emotional interaction and purchasing intention. We need to develop tools that can enhance emotional interaction to increase users' purchasing intentions [62]. Green products can evoke positive consumer emotions [63]. Similarly, designers need to explore and demonstrate the potential of new materials, incorporating market considerations and consumers' feelings into material research [64]. Additionally, the ecological aspects of products should be balanced to advance sustainable business innovation.

4. Conclusions

This paper integrated the MDD method with other sub-methods to develop the new E^2-MDD tool, highlighting the emotional characteristics and ecological performance of natural materials, and validated this method using luffa sponge as a case study. The conclusions were obtained from three aspects of theory, practice, and application.

(1) On the theoretical side, this paper developed a new E^2-MDD tool by taking natural fibres as the main body and based on the two deficiencies of the material-driven design method, which was improved by combining the ecological and emotional factors. The feasibility of the method was verified by using luffa as a raw material.
(2) On the practical side, the four concepts were scored and discussed through the E^2-MDD ring radar column score chart, and the results of the analyses showed that for products made from natural materials, those that were highly accepted by users tended to be closer to the material's original form. The emotional experience generated by users had a similar trend to the ecology of the product in a series of processes such as materials and design. Further, it was verified that materials and design can create a link between ecology and emotion.
(3) In terms of application, this paper showed that the effective use of the method requires adjustments based on the material focus and design objectives, which can serve as a starting point for new methods or tools, and applications in user needs, ecological utilisation, and commercial value are proposed. In conclusion, we hope that our work will inspire and guide stakeholders to lower the barriers to designing with natural materials and promote the advancement of design methodologies.

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