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STICKYNEXUS: Leveraging Sticky Note Interactions to Improve Information Management in Artificial Intelligence-Assisted Design

Effective information collection and management are crucial for creative design. Recently, generative artificial intelligence (GenAI) has become an essential tool for helping designers access multidisciplinary information and expand their creative space. However, the vast amount of artificial intelligence (AI)-generated information can overwhelm designers, complicating the distillation of key insights. Additionally, current conversational AI tools are inadequate in supporting nonlinear design thinking, which is critical for innovative outcomes. To address these challenges, we propose STICKYNEXUS, which supports designers in navigating and synthesizing diverse information from both global and local perspectives when collaborating with AI. STICKYNEXUS enables designers to construct comprehensive design concepts by analyzing relationships among clusters of sticky notes, and it promotes further divergence and iterative refinement based on individual sticky note insights. Our user study ($N = 18$) shows that STICKYNEXUS significantly enhances designers' ability to explore detailed information, unlocking new design possibilities and fostering creative exploration. [DOI: 10.1115/1.4068894]

Keywords: conceptual design, generative AI, creativity support tool

1 Introduction

Advancements in generative artificial intelligence (GenAI) have revolutionized how people access information and knowledge. For instance, prompt-driven text and image generation models enable individuals to rapidly produce detailed stories [1], exquisite paintings [2,3], or personalized UI icons [4]. In the design area, this ability can help designers translate vague concepts into more concrete solutions.

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The creative design process involves collecting and managing large volumes of materials and information [5,6]. As this process constitutes an essential part of the early concept design phase, it significantly influences the definition of the product in later stages and the specification of detailed engineering requirements [7]. Nowadays, designers and engineers increasingly use GenAI to efficiently access multidisciplinary information, including creative stimuli [8–10], design suggestions [11–13], and prototypes [14–16]. However, the influx of artificial intelligence (AI)-generated content also introduces challenges in organizing design information, particularly by exacerbating the ambiguity inherent in the fuzzy front end of engineering design [17]. On the one hand, while AI's rapid generation of diverse content offers designers vast amounts of information, distilling and synthesizing this abundance into innovative ideas remains a challenge [18]. On the other hand, the creative design process is inherently unstructured, and current AI tools still lack adequate support for nonlinear design thinking [19].

Sticky notes are widely used as a material in the early stages of design for flexibly organizing design information [20] and externalizing design ideas [21]. The movement [22,23], clustering [24], merging [25], and splitting [26] of sticky notes, as well as the semantic relevance and spatial arrangement, reflect the mapping and connection of designers' ideas [27]. In scenarios like brainstorming and team collaboration, creativity support tools often adopt the format of sticky notes to organize information, supporting functionalities like overlays and annotations [28], as well as dynamic rearrangement during collaborative activities [29]. As the effectiveness of sticky notes is well proven [30,31], commercial digital whiteboard tools such as FIGJAM,[2] MIRO,[3] and FABRIE[4] have adopted sticky note-inspired interactions, enabling designers to create multiple canvases for organizing diverse design content.

Existing tools have begun to integrate generative AI to assist designers in their creative processes. For example, FIGJAM includes the JAMBOT widget for constructing the ideation process through a mind map-like interface. MIRO offers a wide range of AI-supported templates for organizing content. However, they have not fully utilized the properties of sticky notes to enhance the effectiveness of AI-assisted design (Table 1). Most products focus on generating text and images on sticky notes, summarizing ideas (points 1, 2, and 3). Even when sorting is supported, it is typically limited to basic semantic categorization, without addressing specific analytical needs (point 4). While the quality of generated content has been improved, these products still lack depth in understanding ideas based on sticky note properties (point 5) and in exploring content strategies (point 6).

To address these gaps, this study explores how the properties of sticky notes, such as movement and clustering, be utilized to better associate and organize AI-generated content, with the goal of creating an intuitive tool for information organization. We conducted a formative study to identify the challenges and requirements of integrating GenAI capabilities into the design workflow to support information management and idea development. Specifically, we focused on two aspects: how the properties of sticky notes can be leveraged by AI tools and how AI-generated information can be explored more deeply and presented more clearly. On the basis of the findings, we summarized two types of sticky note properties (Fig. 1), which support design exploration and ideation. These properties enable the re-examination and toggling between elements, the establishment of overarching structural relationships.

On the basis of the proposed strategies, we designed and developed STICKYNEXUS. This tool facilitates the flexible organization of ambiguous information and supports idea exploration from both local and global perspectives. Specifically, STICKYNEXUS helps AI understand designers' ideas by leveraging the properties of sticky notes, enabling AI to assist designers in expanding, decomposing,

Table 1 A comparison of existing online sticky note products with AI features

	BOARDMIX	FABRIE	MIRO	FIGJAM	STICKYNEXUS
(1) Generate multiple sticky notes with AI content	✓	✓	✓	✓	✓
(2) Generate reference images corresponding to text ideas	✓	✓	✓	✗	✓
(3) Summarize overall ideas	✗	✓	✓	✓	✓
(4) Sort sticky notes based on requirements	✗	✗	✗	Limited	✓
(5) Understand ideas based on sticky note properties	✗	✗	✗	✗	✓
(6) Explore ideas from global and local perspectives	✗	✗	✗	Limited	✓

and recombining explored content to produce more potential ideas. Additionally, it allows AI to apply specific design methods to help designers organize overall concepts. As sticky notes accumulate on the shared canvas, the AI interprets clusters and relationships within the canvas. Designers then integrate the AI's interpretations with their own insights, aligning intentions and refining ambiguous ideas. We conducted a within-subject study with 18 design students, using FIGJAM as the baseline for comparison. The results showed that STICKYNEXUS effectively enhances the effectiveness of information management, boosts the creativity of design outcomes, and improves the human-AI collaboration experience. This article presents the following contributions:

(1) We conducted a formative study to reveal opportunities and challenges in using sticky notes properties for managing AI-generated information in creative tasks, and derived corresponding design strategies.
(2) We introduced STICKYNEXUS, a tool that supports the design process by analyzing relationships among sticky note clusters to construct comprehensive design concepts, while promoting further divergence and iterative refinement based on individual sticky note insights.
(3) We conducted a user study to verify the effectiveness of STICKYNEXUS. The results indicated that STICKYNEXUS aids designers in managing complex information and fosters both lateral and vertical transformations of ideas, thereby enhancing the creativity of design outcomes.

2 Related Works

2.1 Information Management for Early Design Process. Design is a typical ill-structured problem, requiring designers to continuously explore design information throughout the design process [32–34]. During the early stages of the design process, designers often integrate diverse information or concepts to establish meaningful connections [35,36]. Innovative solutions typically emerge from the combination of two or more ideas. For example, Yu and Nickerson [37] obtained novel creative solutions by combining different design ideas for chairs through a sketch combination system. Creativity can also be fostered by establishing and reinforcing relationships between different concepts [38]. For instance, Hope et al. [39] expanded creative ideas by transferring purposes and mechanisms. Furthermore, designers also break down complex information into multiple elements to refine concepts, allowing them to reassess the design objects [40,41]. METAMAP [42] explores design instances from three dimensions:

[2]https://www.figma.com/figjam
[3]https://miro.com
[4]https://www.fabrie.com/home

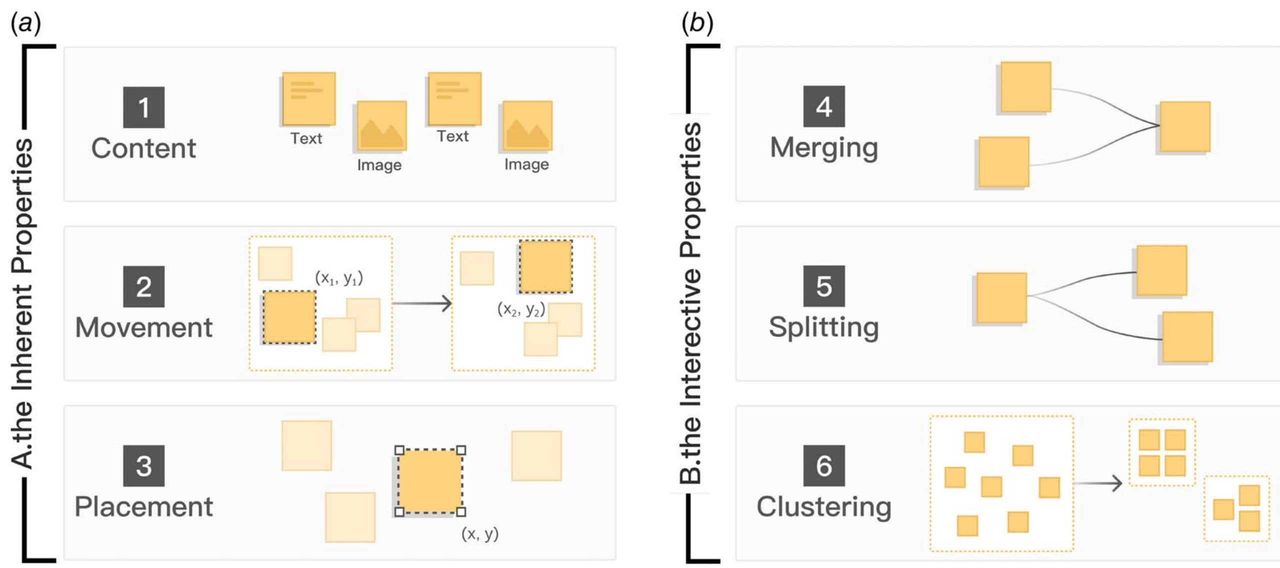

Fig. 1 Properties of sticky note usage summarized from the formative study: (*a*) the inherent properties of sticky notes, including content, movement, and placement, used for understanding design intent; (*b*) the interactive properties of sticky notes, including merging, splitting, and clustering, used for information management and understanding design intent

semantics, color, and shape, fostering the development and convergence of ideas.

An essential goal of design information management is to allow designers to revisit and reinterpret existing ideas. Designers' ideas often freely jump between different types of content, exhibiting nonlinear and discontinuous characteristics [43,44]. Consequently, the organization and understanding of information is also a gradual process; a particular goal may be arbitrarily abandoned or redefined [45]. Research on creativity shows that new insights require time to incubate [46]. Revisiting ideas at certain intervals allows designers to enhance initial understanding and explore alternative interpretations. A study by Dalsgaard et al. [19] confirmed that improved methods for capturing and reinterpreting ideas can benefit designers by helping them retain and activate creativity throughout and after the design process. However, despite investing effort into collecting and representing ideas, designers rarely revisit old ideas and sources of inspiration [47–49]. Therefore, developing tools to assist designers in managing design information is crucial for enhancing both creativity and the quality of design outcomes in the early stages of design.

2.2 Sticky Notes as a Design Material. Sticky notes are widely used as a design material to support the management of information and ideas. Existing research shows that sticky notes support the externalization, exploration, manipulation, and development of ideas and concepts, serving as a "pre-inventive structure" [50,51]. There are subtle and flexible structures and design metaphors between different parts of sticky notes. Even simple movements or local content modifications can imply the development of ideas [52]. Effectively leveraging the flexible structure of sticky notes supports the re-examination and switching between design elements [53,54], including activating and combining parts, selecting and evaluating, dynamically associating parts through classification, reinterpreting parts and the whole, and establishing and exploring overall structural relationships.

Recent studies have explored combining sticky notes with generative AI to support design. For example, He et al. [55] explored the implications and opportunities of incorporating GenAI into sticky note canvases for collaborative tasks and analyzed its impact on addressing idea lulls and creativity homogeneity. Introducing AUGMENTED POST-IT [56] applies sticky notes in augmented reality space to stimulate creative idea generation. A study about adaptive agents [57] examines how sticky note-based interactions in augmented reality can improve the influence of agents on user attention. These studies provide a theoretical and practical foundation for understanding the advantages of sticky note interactions. Building on this foundation, we further explore the strategies for managing AI-generated information using the properties of sticky notes during design processes.

2.3 Design Information Management Systems Based on GenAI. Creativity support tools for managing design information aim to help designers expand and deepen their current ideas and quickly generate integrated and innovative concepts [58]. We summarize the existing information management systems from both local and global perspectives.

In terms of refining local ideas, the previous research has primarily focused on refining text descriptions and image effects, while also supporting the combination and analogy of contents. For example, CREATIVECONNECT [59] focuses on the recombination of conceptual keywords to enhance the efficiency of graphic design ideation. GENQUERY [60] integrates generative models into the visual search process to uncover more diverse outcomes. 3DALL-E [61] provides inspiration for 3D design workflows by expanding keywords related to styles and model components. LUMINATE [62] employs LLMs for the structured generation and exploration of the design space. However, during the initial stages of creative process, designers' concepts are often vague or not fully formed, making it challenging to articulate some design intentions precisely in language. Furthermore, existing mechanisms for managing and interacting with contextual information are relatively inefficient and lack overall consistency.

In terms of organizing overall concepts, existing methods have proposed different visual analysis and understanding methods [63]. For example, Zhong et al. [64] used causal pathway diagrams to enhance human-centered design tasks in the early stages of the design process. PROMPTIFY [65] is a system for iterative prompt exploration and optimization, utilizing stable diffusion model [66] for step-by-step refinement and clustering of existing information. PROMPTMAGICIAN [67] is a multilevel visual analysis system that supports personalized exploration of existing images in a database through the embedding of cross-modal information of recommended images and keywords. Additionally, GRAPHOLOGUE [68] and SENSECAPE [69] use node-based formats for multilayered sensemaking and exploration of existing information. These studies provide viable technical solutions and practical systems; however, they predominantly rely on fixed hierarchical structures (e.g., charts, tree diagrams), which fail to accommodate the iterative and nonlinear nature of the design process. AI systems should not only assist in selecting optimal solutions but also adapt to the evolving design process, providing dynamic support that enhances designers' creativity.

3 Artificial Intelligence-Generated Information Management Strategies Based on Sticky Note Properties

We conducted a formative study to explore how integrating GenAI with sticky note interactions can support the design workflow.

3.1 Study Process. The formative study recruited eight designers, aged 21–25 years ($M = 22.87$, $SD = 1.50$), including three males and five females. All participants majored in industrial design or product design and had experience using GenAI tools like GPT-4,[5] STABLE DIFFUSION,[6] and ERNIE BOT[7] in their daily design tasks. To ensure effective completion of the experimental tasks and to gather valuable insights, we specifically recruited senior students who were either familiar with various design methods or had previously submitted entries to prestigious industrial design competitions like the Red Dot and iF Design Awards.

Our formative study consists of two parts: a design tasks using GPT-4 and an online sticky note whiteboard, and semistructured interviews. In the first part, participants were assigned a task to design "a drone for de-icing power grids" within 30 min. They were encouraged to brainstorm ideas and externalize their ideas on sticky notes. AI-generated content was manually summarized onto notes, and participants iteratively explored solutions with GPT-4 to produce a creative and satisfactory outcome. The think-aloud method [70,71] was adopted throughout. Participants were required to illustrate the final solution with diagrams and simple annotations. In the second part, a 15-min semistructured interview was conducted based on the experimenter's observations. The interview focused on two main questions: "How can AI leverage the properties of sticky notes to enhance collaboration efficiency?" and "How can information organization and presentation be optimized to enable deeper idea exploration?"

3.2 Findings. Observations and interviews revealed that although participants had varying personal habits and faced different design challenges, they consistently acknowledged the value of integrating sticky notes with GenAI for creative tasks. As a familiar medium, sticky notes increased designers" acceptance of AI-assisted work. While clustering and moving notes felt intuitive, participants found it unclear how AI should utilize these behaviors and emphasized the need to communicate with AI through sticky notes.

3.2.1 The Requirement of Having Artificial Intelligence Understand Intent Through Sticky Note Properties. We explored the role of sticky note properties in understanding designer intent. We found that while designers used sticky notes to manage information and clarify their thought, it is not just the content that holds value; the placement and movement of the sticky notes also reflect their thought processes. For instance, P1 mentioned, "The flexible structure of sticky notes allows AI's generated content to seamlessly integrate into my thought process. These contents not only provide solutions to specific problems but also serve as components in the design process that can be discarded, retained, or iterated upon." For designers, utilizing these properties of sticky notes is a natural and intuitive process. Through observations, we identified two types of sticky note properties that participants deemed necessary for AI to utilize:

(1) Inherent properties: Including positioning, movement (P1, P5, P7), and the content itself (as shown in Fig. 1(*a*)).
(2) Interactive properties: Including merging (P1, P4, P5, P7), splitting (P1, P2, P4, P5), clustering effects from stacking multiple sticky notes, and the logical reasoning relationships between clusters (P2, P4, P5, P6) (as shown in Fig. 1(*b*)).

3.2.2 The Requirement of Breaking Through Existing Information Boundaries in the Creative Process. Despite having clear design concepts, designers often struggled to refine ideas. They may lack insights on how to further develop their designs based on existing content and require external guidance. AI plays a crucial role in facilitating lateral and vertical expansion of ideas through sticky notes (P2, P4). P2 reflected on the multidimensional nature of the task, "Designing a drone that de-ices through mechanical vibrations made me think of common striking behaviors, but realistically, this function also involves flexible structures, lightweight materials, and position-detecting sensors." P4 added, "Besides horizontal expansion, I need AI to delve deeper vertically; what could be the further possibilities of the current idea?" These insights align with De Bono et al. [72], who highlight how lateral and vertical thinking foster idea development in information organization. Additionally, participants expected AI to take an indirect approach to help break mental fixation by not only providing solutions but also stimulating their innovative thinking through questions. For example, P7 asked AI to pose questions, stating, "I think AI should proactively pose questions to me, just like I'm working with my team to advance design concepts. AI doesn't always need to comply with me."

In summary, designers expect AI to play a more active and interactive role in the design process, refining ideas through counter-questions, lateral expansion, reinterpretation, and vertical expansion.

3.2.3 The High Effort of Gaining Insights From Fragmented Information for Idea Refinement. Although sticky notes helped designers visually navigate and filter ideas, the large volume of AI-generated content made it harder to manage fragmented information. The design process often involves continuous weighing and comparing of multiple pieces of scattered information. P2 explained, "Although I have obtained more design proposals, some contain similar functions, while others are completely different, requiring me to choose one." We found that participants manually broke down and reorganized the information to refine their ideas. For instance, P5 categorized the drone's chemical de-icing module into three aspects: location, material, and sensors, and then organized AI-generated text and images into keywords and graphic details under each category. By combining keywords from different categories, the AI provided several alternative solutions. P5 added, "This bead-stringing-like activity allowed me to compare multiple similar but differently solving proposals, which is crucial in the later stages of concept iteration."

Therefore, participants considered it essential to have a system that supports quickly linking and comparing different design elements, while also allowing for easy modification to refine the final design.

3.2.4 The Difficulties in Achieving Holistic Interpretation With Complex Design Tasks. Participants expressed a need for AI to provide a holistic interpretation of the design context. P3 mentioned that when deeply focused on specific problems, it becomes difficult to maintain a macrolevel understanding of the solution, which may lead to deviations or errors later in the process. P5 shared a similar view, adding, "Quickly integrating design concepts can reduce a lot of mental effort in the design process."

[5]https://openai.com/index/gpt-4/
[6]https://stablediffusionweb.com/
[7]https://yiyan.baidu.com/

To systematically manage design information, holistic interpretations should be based on specific design methodologies. However, due to the complexity and variability of real-world design scenarios, participants found it difficult to apply the analytical methods they learned to their projects. P1 mentioned, "I wish AI could tell me what methods it uses to interpret my design ideas." P3 agreed, adding, "It feels more reliable when design methods are incorporated. Meanwhile, I can also compare analytical conclusions from different methods."

3.3 Design Strategies and Goals. On the basis of the findings from the formative study, we proposed two strategies for developing a design-assisted tool that integrates the advantages of sticky note interaction and GenAI. Specifically:

(1) Local information organization and reinterpretation: utilizing multidimensional expansion and the splitting and reorganization of information as strategies for AI to organize local information, thereby promoting the reinterpretation of local content.
(2) Global understanding and alignment from a whole perspective: utilizing the inherent and interactive properties of sticky notes as strategies for AI to understand the design intent, providing a cohesive and holistic perspective.

Based on existing information, AI leverages the properties of sticky notes to interpret design intent and visualizes it according to specific method requirements. This understanding serves as a foundation for providing more detailed support in the exploration of the local content. By looping between global and local perspectives, we aim to achieve flexible and efficient information management. The specific four design goals are as follows:

(G1) *Supporting information expansion in the design process to stimulate designers' creative thinking.* On the basis of observations from formative study and participant feedback, we propose expansions in four dimensions: question, diversification, interpretation, and deepening. This helps designers to question or make suggestions based on existing information, thereby reducing psychological dependence on AI and stimulating a more creative thought process.
(G2) *Providing methods for local information reorganization and decomposition to support idea refinement.* Integrating AI insights into the reorganization and division of local information enhances fine-grained adjustments and rearrangements, helping designers to visually discern potential outcomes and reduce the costs of idea construction.
(G3) *Leveraging the inherent and interactive properties of sticky notes to enhance AI's understanding of the designer's thought process.* By recording the position, movement, content, and arrangement of sticky notes, using them as input parameters, AI system can better manage ideas and support creativity during the design process.
(G4) *Providing channels for personalized design methods to facilitate holistic interpretation.* Offering a variety of design analysis methods and introducing a history feature helps designers compare and scrutinize design issues from different analytical perspectives. The system should also allow designers to customize analysis methods according to project requirements.

4 STICKYNEXUS

By drawing from these findings, we designed and implemented STICKYNEXUS, a sticky note-based system featuring two modes: global mode (Fig. 5) and local mode (Fig. 2).

4.1 Multidimensional Expansion From a Local Perspective (for G1). *Providing expansion suggestions in four directions.* Based on the current task (Fig. 2, ①), STICKYNEXUS provides a multidimensional expansion function panel (Fig. 2, ②) to assist designers in their design process. Specifically, designers can select any sticky note that represents an idea, such as "(power grid de-icing drone) high-frequency vibrations quickly shatter ice," and request AI-generated suggestions in four aspects: question, diversification, interpretation, and deepening. Designers can click on helpful sticky notes in the panel to add them to the canvas (Fig. 2, ②), such as "Consider the impact of vibrations on the drone's structural integrity and how to ensure durability (Question)," "Focus on cost control by using durable materials to reduce maintenance frequency (Diversification)," "Explore adjustable frequency vibrations to adapt to different environments and ice thicknesses (Interpretation)," and "Add a camera for visual feedback on ice conditions (Deepening)." Designers can use this information to refine existing notes or generate more ideas, furthering expand the current canvas concepts.

Prompts design. Figure 3 illustrates the prompt engineering pipeline for AI-generated multidimensional suggestions. To ensure the generated content meets the requirements, we use zero-shot prompting for the input <Current Info> as outlined. The system first requires the LLM to understand the prompt and then outputs a corresponding list of responses. To enhance the accuracy of the results, the prompts request the LLM to explain why these suggestions align with the current expansion dimensions. The generation of the 16 suggestions is completed within 5 s.

4.2 Splitting and Reorganization From a Local Perspective (for G2). In the canvas, designers can use the "Splitting and Reorganization" feature panel (Fig. 2, ③) to further refine design information. This feature comprises two core components: the "splitting" function, which breaks down the sticky note content into independent design consideration dimensions, and the "reorganization" function, which explores and creates various combinations based on selected words, while integrating details randomly provided by AI.

Splitting keywords from explored images and texts. Designers select a portion of sticky notes, upon which the system automatically extracts key points $\{k_1, k_2, \ldots, k_m\}$ and identifies corresponding keywords $\{w_1, w_2, \ldots, w_m\}$ (Fig. 4, ①). For visual data, the system performs an analysis of the reference images or sketches provided by the designers (see Fig. 2, ③), extracting key points and corresponding keywords in a manner similar to text processing. To ensure the image conclusions align with the current design approach, we derive key points from image information focusing on four main aspects—product requirements, functionality, design, and structure, based on observations from the formative study. Designers can click keywords to add them to the "elected ideas" text box, which serves as input for the reorganization process.

It is important to note that while multiple sticky notes may share the same key point, such as "environmental condition collection," they may feature different specific descriptions, such as "road lighting" or "snow detection." To manage the complexity and variety of design key points and to avoid the extraction of irrelevant keywords, we provide the LLM with few-shot examples (Fig. 4.②) to enhance its accuracy in identifying key points. The LLM then ranks the keywords associated with each key point by relevance, displaying only the top six on the interface.

Reorganizing keywords to produce detailed solutions. After reviewing multiple key points, designers can select the relevant keywords (Fig. 2, ③). The system then generates four distinct options, presented in both text and image formats. Designers can choose the most suitable option to add as a new sticky note on the canvas. Different combinations of key points can create various focus-oriented solution combinations, allowing designers to visually assess different scheme references (Fig. 4, ③). In the prompt, we ask AI to introduce differentiation into the four solutions by randomly selecting keywords from varying levels of similarity, ensuring diverse choices.

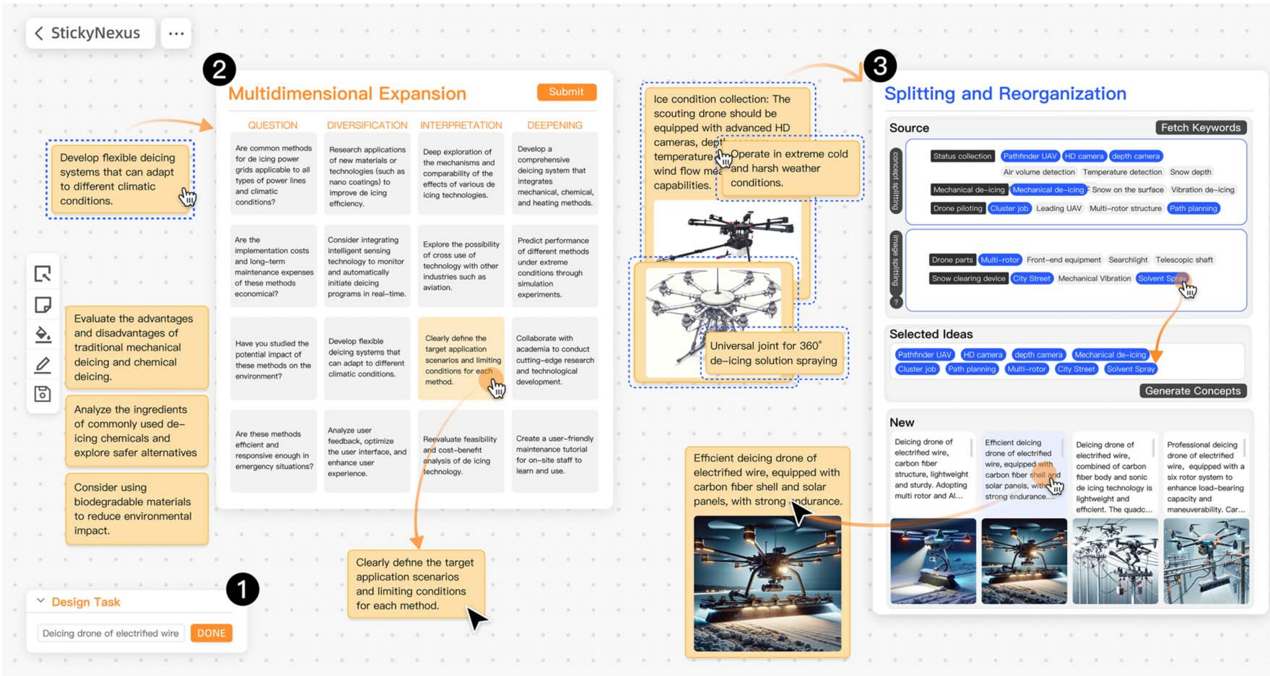

Fig. 2 The UI interface of StickyNexus for the local mode. The sticky notes are distributed across the canvas, and those outlined by dashed borders indicating designer' selection. ① After obtaining the current design task, StickyNexus offers two local strategies: ② "multidimensional expansion" provides designers with deeper and more divergent inspiration; ③ "splitting and reorganization" decomposes and combines existing information to generate multiple solutions.

4.3 Information Clustering and Multiversion Comparison From a Global Perspective (for G3 and G4). Building a cohesive concept from scattered ideas can be time consuming for designers. StickyNexus employs specific methods to manage ideas and offers comparative features for further optimization.

Using sticky note properties and custom methods to interpret design intent. One challenge of AI in assisting the design process is that AI might not fully grasp the designer's overall vision before providing feedback. To address this, StickyNexus uses sticky note clustering and relationship analysis to interpret design intent. By using the "Global Understanding" panel (Fig. 5, ②), designers can invoke AI to rearrange canvas information based on the specified design analysis methods, producing interpretations of idea clusters and their relationships (Fig. 5, ①). These include editable titles, explanations, and associated notes, allowing designers to refine AI output. Designers can also request AI to interpret the layout of their constructed canvas based on the inherent and interactive properties (clustering) of sticky notes. This overall idea interpretation serves as part of the local strategy's prompt, which supports local information management and strengthens human–

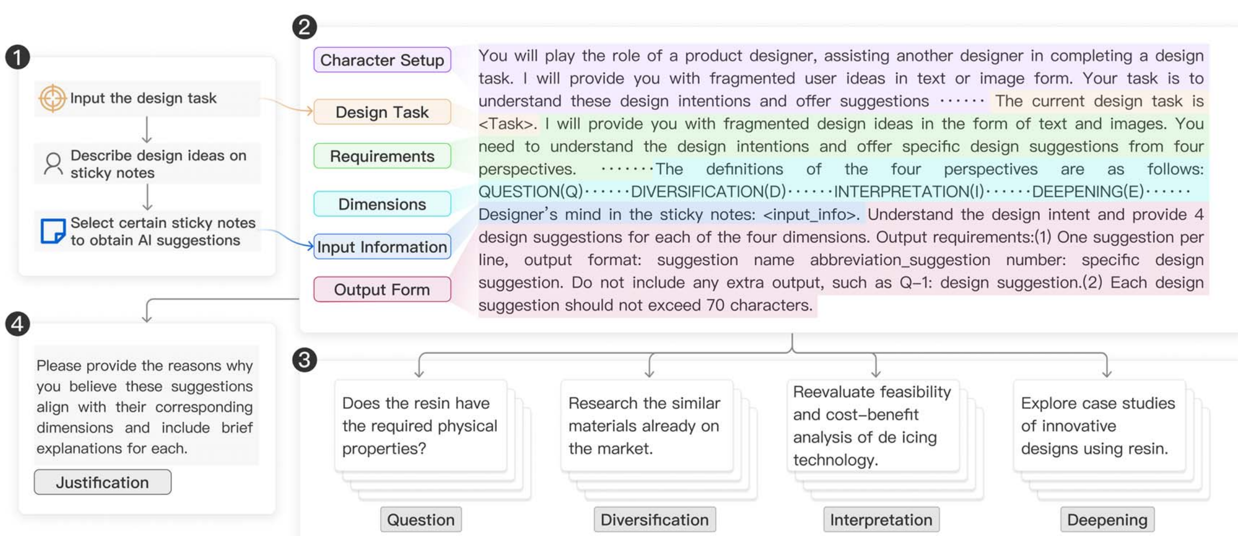

Fig. 3 The implementation method for multidimensional expansion from a local perspective. ① Current design tasks and the selected sticky note are used as part of the prompt input. ② Specific prompts include character setup, design task, requirements, dimension definitions, input information, and output form. ③ Expansion suggestions across four dimensions are provided for designer selection and regeneration. ④ Further explanation is requested to enhance content accuracy.

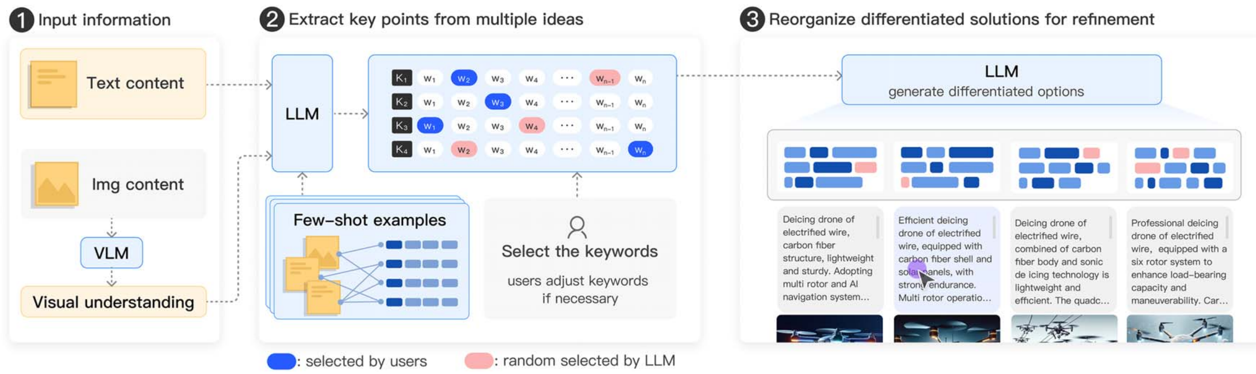

Fig. 4 The implementation method for splitting and reorganization from a local perspective. ① The processing of input information. ② The key point extraction performed by the LLM based on few-shot examples is explained, and designers select the keywords they find suitable, with the LLM randomly selecting some as part of the differentiated solutions. ③ The differentiated solutions generated by the LLM through reorganization.

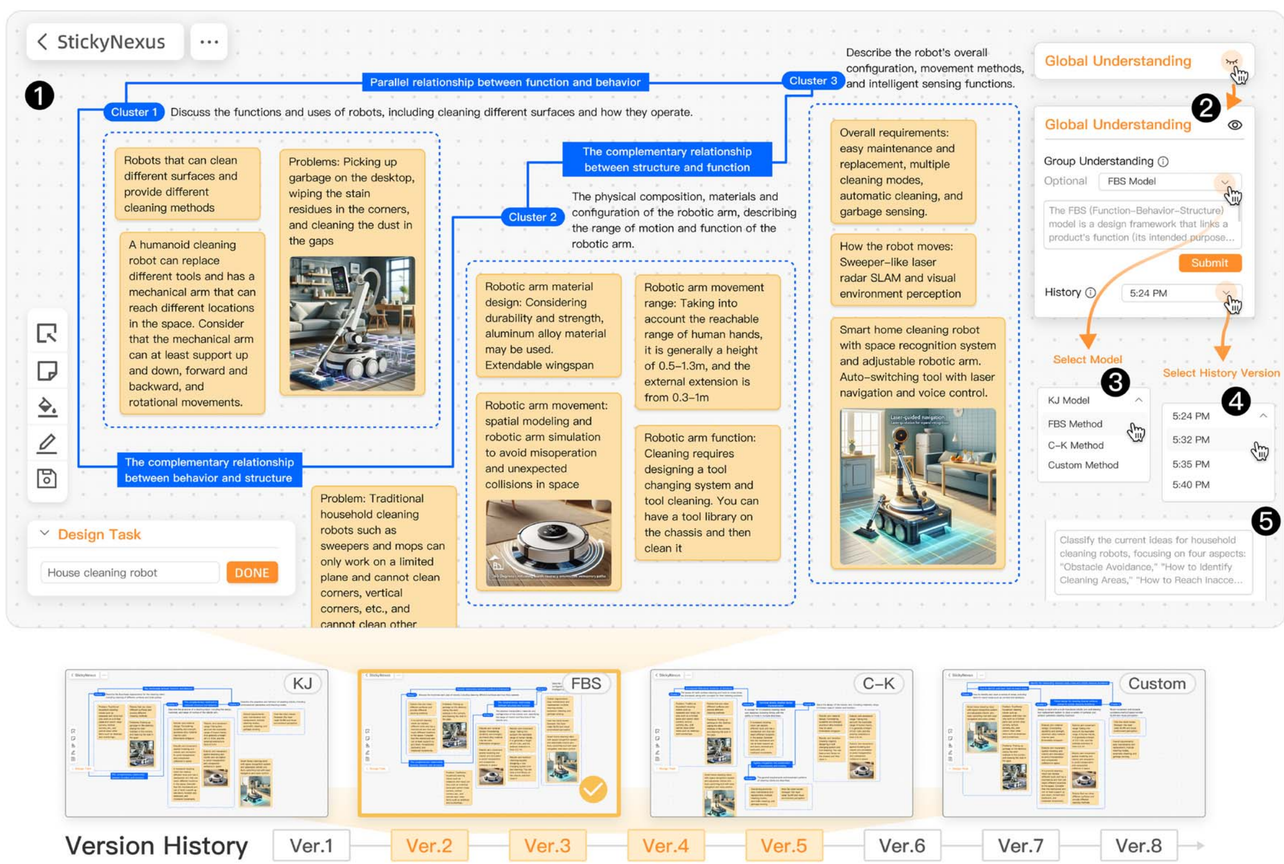

Fig. 5 The UI interface of STICKYNEXUS for the global mode. In the "Global Understanding" panel, designers can select either preset or custom design methods. ① AI's understanding of canvas content, providing specific explanations of clusters and relationships based on the properties of sticky notes. ② Functions for selecting design methods and comparing different interpretation approaches. ③ More methods. ④ More history records. ⑤ An example for custom method.

AI alignment. To enhance explainability and theoretical grounding, STICKYNEXUS supports predefined and customizable design methods. Designers can choose among commonly used conceptual design methods, such as the KJ method, FBS model, or CK theory. These three widely-used conceptual design methods help systematically organize ideas to develop conceptual solutions (Fig. 5, ③). Or designers can also define custom logic (Fig. 5, ⑤) to guide AI in clustering and interpreting sticky note content.

Refining idea through comparison. Designers can retain and review multiple interpretations—whether generated by AI or created manually—based on different design methods (shown at the bottom of Fig. 5). By comparing these versions over time (Fig. 5, ④), they can iteratively refine clusters and relationships to form a cohesive concept.

Prompts design. To support accurate understanding of sticky note clusters and relationships, we developed a structured prompt pipeline inspired by the formative study. First, our AI employs structured output capabilities to extract detailed texts about sticky notes properties, including "ID_number," "location_X," "location_Y," "text," and "image_descriptions." "image_descriptions" contained key parts of the product and their detailed descriptions. We then align this structured text with the sticky note's textual content, selecting only the relevant parts for further analysis and disregarding the rest. Following this, we used a step-by-step approach

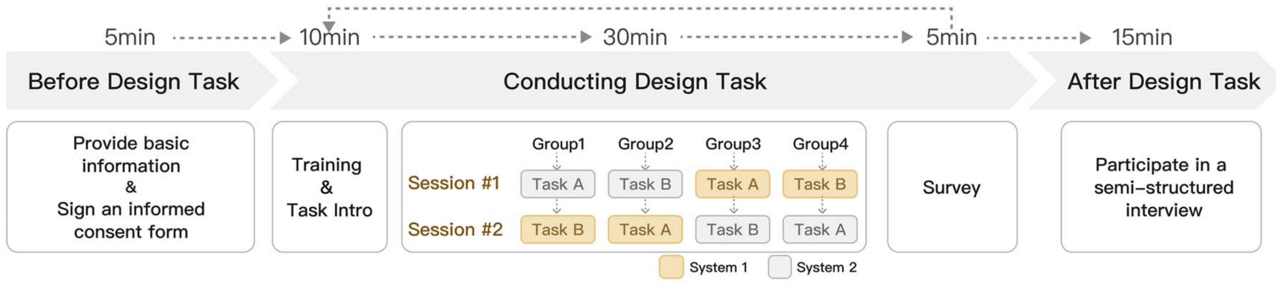

Fig. 6 The procedure of the user study

based on chain of thought (CoT) to obtain the understanding of the clusters and their relationships. To ensure precise categorization of sticky notes discussing similar topics, rather than merely grouping by semantic similarity, we provided several examples for AI to perform in-context learning. Each cluster was checked for anomalies (such as blanks or duplicates) and classified as outliers if any were found. Based on the classification of the clusters, AI interpreted their relationships and output in a specified structured format.

4.4 Implementation Details. STICKYNEXUS is a web-based system, implemented using React, the Graph Editing Engine of AntV,[8] and a PYTHON FLASK[9] backend. The Graph Editing Engine of AntV handles both interaction-responsive nodes and global understanding visualizations. Visualizations can be saved as historical views in the database, which designers can retrieve and render in real time as needed. These operations rely on the Graph Editing Engine's built-in data storage and retrieval capabilities. The PYTHON FLASK backend calls the GPT-4o[10] and DALL-E-3[11] models to support generation.

5 User Study

To verify the effectiveness of STICKYNEXUS, we conducted a within-subject comparative study with 18 participants. We specifically focus on how designers revisit information and iterate on their ideas during the design process using the system and the baseline. We address the following research questions:

RQ1: Does STICKYNEXUS help designers better effectively manage and utilize information during the AI-assisted design process?

RQ2: Does STICKYNEXUS support flexible design thinking and enhance designers' creativity?

5.1 Baseline. We selected FIGJAM as the baseline system for comparison with STICKYNEXUS, as it is a feature-rich product that includes an AI-supported sticky note system. FIGJAM provides a chatbot, JAMBOT (Fig. 12 in Appendix A), to help participants expand their ideas into mind maps and offers a simple categorization feature for sticky notes, such as brainstorming, questioning, and summarizing, based on their own prompts. Participants were permitted to use DALL-E for text-to-image generation while working with the baseline system. To reduce bias, we did not inform participants which of the two systems was the baseline, emphasizing the focus on interaction features. We aim to compare and analyze the two systems based on different strategies to understand their impact on design information management.

5.2 Participants. We recruited 18 participants (10 females, 8 males) from a local university through social media platforms. Participants met the following conditions: (1) majoring in design-related majors (including product design, industrial design, and design science) and having design experience of over 2 years; (2) having experience using generative tools to enhance the functionality and aesthetics of the product design in their daily work.

5.3 Procedure. Figure 6 depicts our user study procedure. Participants first signed informed consent forms and provided basic information. Then, participants were randomly assigned to four groups, completed two design tasks: a household cleaning robot (task 1) and a city green maintenance robot (task 2). These tasks were adapted from design competition entries and required participants to propose innovative conceptual solutions. We systematically counterbalanced the order of system usage and task execution to reduce biases introduced by order effects. While detailed technical specifications were not required, participants were expected to formulate conceptual ideas concerning appearance, functionality, or basic structure. Each task began with a 10-min tutorial covering system usage and task objectives. Participants then had 30 min to iterate on their designs, culminating in a final sketch and a brief bullet-point description focusing on functionality, structure, or appearance. The think-aloud protocol was employed throughout, and the tablet screen was recorded. After each task, participants completed a questionnaire to evaluate their experience with the system. The study concluded with a semistructured interview to gather additional feedback. The entire session lasted approximately 110 min.

5.4 Metrics. We developed a custom questionnaire (Table 2) to assess participants' experiences with the two systems. The items in this questionnaire were directly aligned with our system design goals and were rated using a seven-point Likert scale. We employed the creativity support index (CSI) [73] to assess the creativity of participants' outputs in the task. Due to the single-person task, we modified the "collaboration" factor to "collaboration with AI." In addition, to analyze participants' thinking processes, we encoded the transcripts obtained from their think-aloud sessions. Specifically, we analyzed participants' lateral and vertical idea transformations [72] to evaluate STICKYNEXUS's impact on the design process. This analysis drew on the concepts of "design as search" and "design as exploration" as discussed in Ref. [74]. Two authors, each with over four years of design experience, established and agreed upon the coding standards. They independently coded the data and resolved any discrepancies through discussion until a consensus was reached.

For quantitative data, we initially assessed distribution normality using the Shapiro–Wilk test, followed by paired-sample t-tests for normally distributed data and Wilcoxon signed-rank tests for non-normal datasets.

6 Results

6.1 RQ1: Information Management Support

6.1.1 Quantitative Results. Table 2 and Fig. 7 show that STICKYNEXUS outperformed the baseline across all key aspects of information management.

[8]https://x6.antv.antgroup.com/
[9]https://flask.palletsprojects.com/en/stable/
[10]https://platform.openai.com/docs/models/gpt-4o
[11]https://openai.com/index/dall-e-3/

Table 2 The self-customized questionnaire for evaluating the effectiveness of information management

Aspects	Evaluation questions
Local divergence	EQ1: Does the system help me expand my design thinking based on the current information? EQ2: Does the system help me analyze the relevance and potential significance of local information?
Local in-depth exploration	EQ3: Does the system help me better explore design ideas from the fragmented information? EQ4: Does the system help me identify and improve gaps in existing information?
Comprehensive analysis and iteration	EQ5: Does the system accurately cluster the content of sticky notes? EQ6: Does the system supports me in comparing and supplementing ideas retrospectively? EQ7: Does the system help me integrate information across dimensions?

For local divergence, STICKYNEXUS scored higher in analyzing local information ($p < 0.01$) from multiple perspectives. Although there was no significant difference in the scores for expanding thinking based on current information, STICKYNEXUS ($M = 5.83$, $SD = 1.10$) still had a higher average score (baseline: $M = 5.27$, $SD = 0.89$). In terms of in-depth exploration, participants reported that STICKYNEXUS provided better support for exploring ideas from fragmented information ($p < 0.001$) and improving upon existing information ($p < 0.001$) compared to the baseline system. For comprehensive analysis and iteration, STICKYNEXUS helped participants better interpret cluster relationships ($p < 0.01$), compare and revise ideas ($p < 0.05$), and organize information across dimensions ($p < 0.05$).

6.1.2 Qualitative Results. STICKYNEXUS helps information management at multiple levels of granularity. Participants reported that these features supported nonlinear thinking. They could explore and organize information at multiple abstraction levels (Fig. 8), ranging from individual keywords and sticky notes to groups and overall design concepts. Although the baseline system offers a "summarize" function, it focuses on individual sticky note (P15). In contrast, STICKYNEXUS's "Splitting and Reorganization" feature enables participants to decompose sticky note information into specific keywords (P15), and "Global Understanding" feature enables participants to explore and develop ideas clusters further (P2). Figure 13 in Appendix B shows that the three core functions of STICKYNEXUS were extensively utilized by participants during their design activities.

STICKYNEXUS facilitates rapid consolidation of ambiguous information. Participants praised the "Global Understanding" feature for its effectiveness in quickly synthesizing information. For example, after P13 produced various fragmented pieces regarding the design requirements of a home cleaning robot, the "Global Understanding" feature quickly grouped these into four clusters: *current scenario issues*, *suggestions for improvements to existing cleaning robots*, *pet-friendly design features*, and *potential technical challenges*. P13 noted that independently summarizing these ideas could have been both time consuming and less accurate. P8 utilized AI-generated clusters as a foundation, subsequently refining cluster descriptions and adjusting internal sticky note details according to his interpretation and design priorities. Furthermore, P14 mentioned that he relied on the generated cluster titles as reference points to guide deeper analysis and subsequent decision-making processes.

The dimensions identified for local divergence are concise yet effective. Participants highlighted that the expansion across four dimensions, aligned with design thinking principles, facilitated idea association and divergence, offering greater inspiration than the baseline. P2 explained that this was because humans typically have limited capacity for expansion, and added, "AI can also associate different content based on similarity and spatial proximity. For example, it questioned the feasibility of the structure based on my material requirements, which was very helpful for me." However, participants also raised concerns regarding cognitive load. P9 noted that processing information across all four dimensions imposed considerable cognitive demands, and P8 emphasized that effective expansion still required an initial idea. Moreover, P9 observed that although AI-generated expansions made designs appear more comprehensive, the suggested features were not always practical or applicable.

6.2 RQ2: Design Thinking Support and Creativity Support

6.2.1 Quantitative Results. According to the Wilcoxon test, the CSI for STICKYNEXUS ($M = 71.76$, $SD = 11.62$) was significantly higher than the baseline ($M = 50.33$, $SD = 14.55$). As shown in Fig. 9, our system significantly outperforms the baseline in exploration (Q2: $p < 0.05$; Q7: $p < 0.05$), expressiveness (Q3: $p < 0.01$; Q8: $p < 0.05$), results worth effort (Q5: $p < 0.001$; Q10: $p < 0.01$), and collaboration (Q11: $p < 0.01$; Q12: $p < 0.05$). Meanwhile, it is comparable to the baseline in terms of enjoyment and immersion.

We also analyzed the coding results presented in Fig. 13 to assess the contributions of both systems to lateral and vertical thinking transformations in the design process. The summary of these transformations is presented in Table 3. First, participants accepted more lateral ideas from AI in STICKNEXUS (Num = 59) compared to the baseline (Num = 10). At the same time, STICKYNEXUS encouraged a longer step of lateral thinking (average step count: 2.11; maximum step count: 7), suggesting that our system effectively stimulated participants' active thinking. Conversely, the baseline primarily

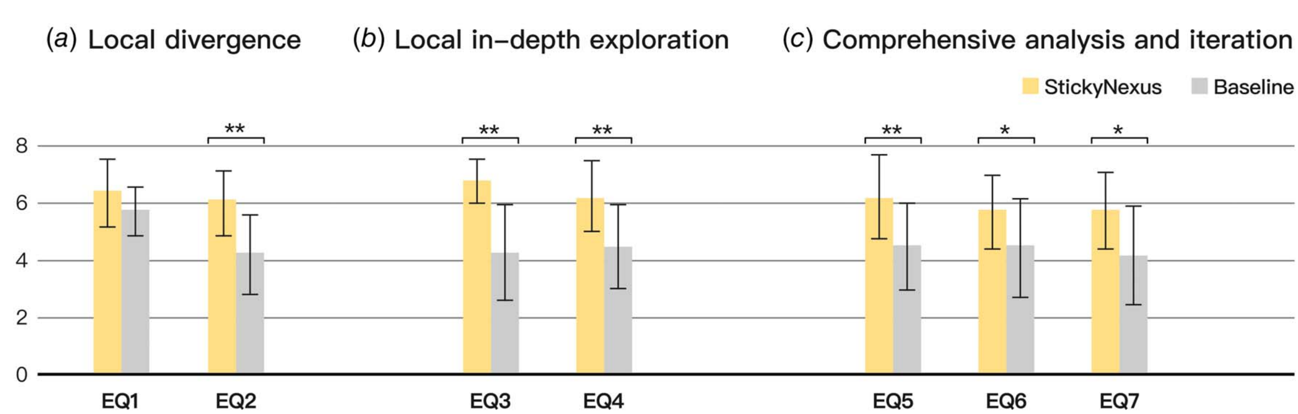

Fig. 7 The quantitative results of the self-customized questionnaire (* indicates $p < 0.05$ and ** indicates $p < 0.01$)

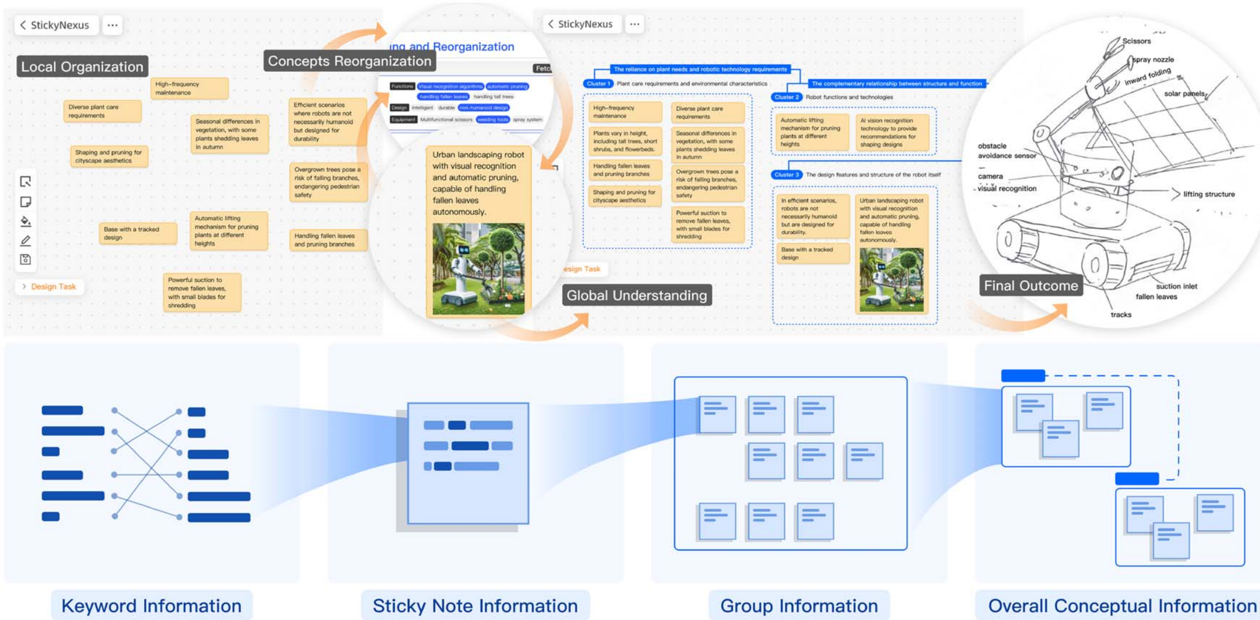

Fig. 8 This multilevel flexible exploration. Participants can freely jump between the four levels of granularity in design information. Take P12's design process as an example: P12 repeatedly broke down sticky note content and filtered key information to refine the core idea. Then, using the global understanding feature, P12 iteratively developed a well-defined solution by comprehensively analyzing and adjusting cluster content.

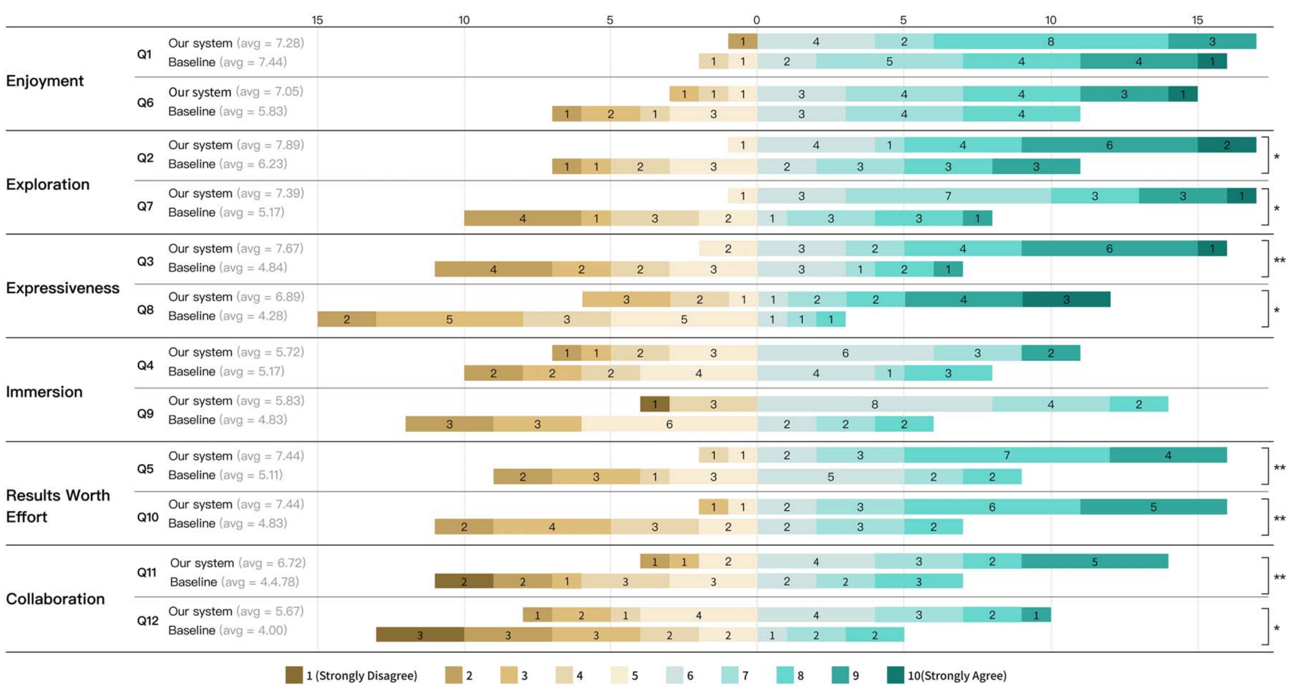

Fig. 9 Results of the questionnaire regarding the creativity support of both systems (* indicates $p < 0.05$ and ** indicates $p < 0.01$)

encouraged specific, vertical idea transformations, thus limiting associative and reflective thinking. Second, when the number of lateral and vertical transformations was similar between both systems, the proportion of shifts between lateral and vertical transformations in StickyNexus (rate = 31.65%) were significantly higher ($p = .03$) than in the baseline (rate = 29.44%). To further explain these results, we provide qualitative insights in the following section.

6.2.2 Qualitative Results. Multifaceted interpretations support in-depth creative exploration. User interviews (Fig. 10(*b*)) indicate that although the images were AI generated, they remained faithful to participants' fragmented textual inputs and incorporated diverse AI interpretations, gave meaningful reinterpretations. For example, P11 mentioned during the task, "I saw the combination of tracks and wheels in the image, which caught my attention," and "The image made me realize that the water storage function of the greening maintenance robot takes up a lot of space and may not be very feasible." This may explain why the interaction paths in StickyNexus were longer than those in the baseline system (Fig. 13).

Theme	Code	Participants
A. The Impact of Visual Information Presentation using Sticky notes	**Code1: Information Processing and Presentation**	
	1 Sticky note clustering and relationships quickly present key ideas.	P1, P6, P7, P9, P10, P13, P14, P17,
	2 Quickly filter scattered information to identify important details.	P18
	3 Enhance design focus and reduce the chances of missing critical information.	P2, P4, P11, P14, P15
	4 Concerns about information overload.	P1, P2, P4, P7, P8, P11, P13, P14, P18
	5 Focus on extracting value from browsing, but it affects thinking concentration.	P7, P8, P14
		P12, P17, P18
	Code2: Design Process Management	
	1 No fixed workflow, supports personalized and flexible design.	P3, P7, P11
	2 Historical comparison of ideas for process tracking and refinement.	P2, P3, P5, P10
	3 Design process tracking and management are less efficient than hierarchical structure.	P5, P8, P9, P12, P15, P17
	Code3: Non-linear Thinking	
	1 Shifting and connecting information to promote relational thinking.	P4, P8, P9, P14
	2 Free organization breaks linear thinking patterns, enabling easier iteration.	P1, P2, P3, P4, P6, P7, P11
B. Facilitation of Idea Development through System Features	**Code4: Integration and Convergence**	
	1 Integrate design solutions based on knowledge of design methods.	P4, P8, P14
	2 Maintain overall structural consistency through a macro perspective.	P6, P9, P11, P14, P18
	3 Quickly combine key elements to reduce redesign efforts.	P2, P4, P11, P12, P14, P15, P18
	4 Support reflection on existing ideas to improve solution feasibility.	P1, P3, P9, P10, P11, P13, P14
	Code5: Cognitive Divergence	
	1 Multidimensional information expansion helps uncover potential design directions in the early stages.	P2, P4, P5, P6, P9, P10, P11, P18
	2 Discover new elements and provide fresh jumping points for thinking.	P1, P2, P4, P11
C. Collaboration with AI in the Design Process	**Code6: Trust and Collaboration Efficiency**	
	1 Confidence in information sharing and synchronization boosts collaboration trust.	P2, P6, P7, P8
	2 AI generation based on theories and sticky notes increases controllability.	P6, P12
	3 Clear distinction between content contributed by AI or yourself.	P11, P17, P18
	4 AI suggestions may disrupt the thought process.	P6, P9, P17, P18
	5 Concern about AI overloading with unnecessary features.	P9

*The gray blocks represent drawbacks.

Fig. 10 The result of the thematic analysis. We have categorized the conclusions of the thematic analysis into three types: the impact of the system's visual form, the system's support for idea development, and the experience of collaborating with AI. The color gray indicates potential drawbacks mentioned by the participants.

Flexible structures foster the discovery of creative possibilities. STICKYNEXUS' flexible format made it easier to identify connections between nodes (Fig. 10(*b*)).

This also explained why, compared to the baseline, STICKYNEXUS better leveraged AI to unleash participants' creativity, facilitated more idea transformations, and reduced the rigidity of AI-provided suggestions (Table 3). It promoted better interpretation of participants' own information, allowing originally ambiguous ideas to be explored with more diverse explanations.

Table 3 Quantitative comparison between two systems for supporting lateral and vertical thinking transformations

		STICKYNEXUS	Baseline
Lateral Transformation	Designer/AI	57/59	54/10
	Average per participant	6.44	3.56
	Average step count	2.11	1.75
	Maximum step count	7	4
Vertical Transformation	Designer/AI	83/155	70/114
	Average per participant	13.22	10.22
	Average step count	3.65	4.55
	Maximum step count	28	14
Shifts between Two Types	Average count	6.22	4.06
	Shift rate	31.65%	29.44%

Note: Step count refers to the number of consecutive executions of the current thinking type.

STICKYNEXUS reduces the burden of creative expression. P14 suggested that participants often struggled with unclear design details. The flexible presentation of sticky notes, supported by splitting and reorganization, helped filter and focus ideas. This enabled participants to identify key elements that cannot be expressed visually and supplemented them with inspiration from AI-generated images. P2 also highlighted frequent use of the Question dimension during early-stage design, allowing free expansion across sticky notes and clusters. This significantly reduced the mental effort required for lateral ideas exploration.

Thinking shifts help prevent creative fixation. P13 stated, "STICKYNEXUS' expansion strategy indeed stems from design thinking, incorporating dimensions such as Question, Diversification, Interpretation, and Deepening. These dimensions enable AI to foster broader discussion around the problem space, rather than focusing solely on specific solution suggestions." In contrast, the baseline mainly emphasizes detailed solutions. STICKYNEXUS' global strategy helped reconsider whether anything was missed or insufficiently explained, also promoting both lateral and vertical thinking development. P9 mentioned that the global strategy effectively promoted revisiting information (Fig. 10(*a*)), and added, "Although AI sometimes makes mistakes, with categorization not meeting expectations, it helped me gain better control over the overall design process." This demonstrated that our system enabled participants to better leverage AI to organize and develop their existing ideas, rather than relying solely on AI-generated suggestions.

7 Discussion

7.1 Different Creative Process Exploration Patterns Driven by Artificial Intelligence or Designers. To further discuss how different strategies influence idea exploration, we analyzed coding

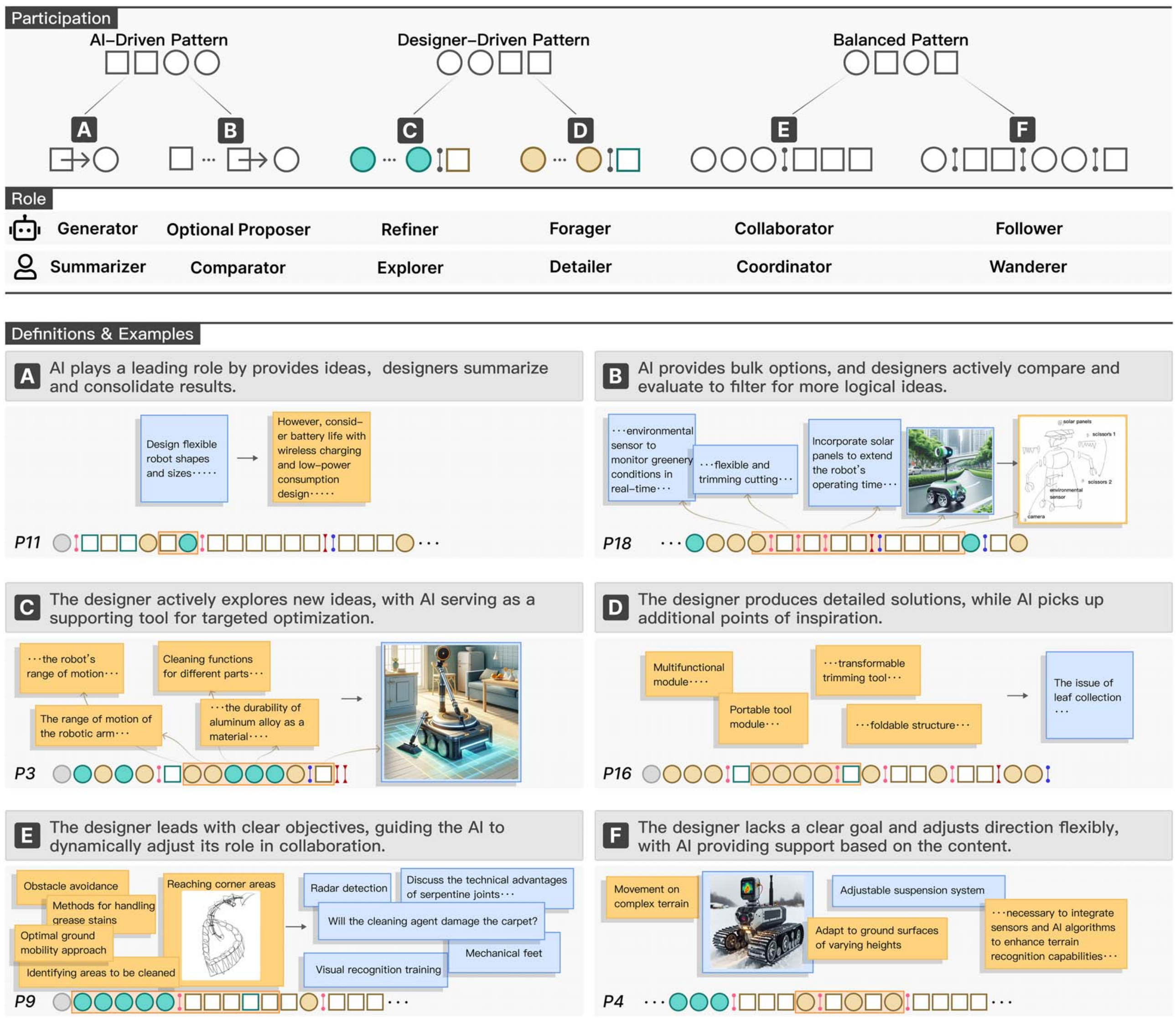

Fig. 11 The exploration patterns. We categorized the sticky note-based collaboration process into three patterns based on different forms of participation, further refining them into six types by interactive turns. The roles of designers and AI in different patterns have been further summarized, along with definitions and examples for each pattern.

results of participants' thinking transformations and system usage, and identified six patterns (Fig. 11).

The *AI-driven exploration pattern* is led by AI-generated content, with designers exploring ideas inspired by the AI. In pattern A, AI dominates content generation, and designers quickly accept and summarize it, enabling rapid exploration but limiting independent thinking. Pattern B highlights a more deliberate approach, where designers critically evaluate and synthesize AI-generated content, fostering deeper engagement. The *designer-driven exploration pattern* originates from designer's own ideas. We identified two behavior patterns. In pattern C, designers perform broad lateral divergence followed by vertical refinement with targeted AI support, requiring strong analytical skills. In pattern D, designers iteratively refine ideas, integrating AI suggestions for inspiration, though the quality of lateral expansions can vary. The *balanced exploration pattern* reflects equal collaboration between human and AI. In pattern E, designer maintains clear goals, while AI dynamically adapts. In pattern F, the designer takes on a "wanderer" role, frequently adjusting goals and drawing inspiration through interactions with the AI. While pattern F offers flexibility, it may lead to repetitive and inefficient exploration.

We compared the differences in exploration patterns between StickyNexus and the baseline system. In AI-driven patterns, pattern A appeared 10.47% more frequently in the baseline, likely due to its hierarchical interaction style that promotes passive acceptance of AI suggestions. StickyNexus exhibited more pattern B usage, as its global-local strategies encourage filtering and deeper evaluation of AI output. According to designer feedback on contribution (Code 6-3 in Fig. 10), recognition of creative ownership varied. In pattern A, where AI led the process, designers tended to credit AI with the creative contribution. In pattern B, where designers engaged more critically, they viewed themselves as the primary contributors. For designer-driven exploration, both systems showed similar frequencies of pattern C. However, StickyNexus significantly outperformed the baseline in pattern D, demonstrating its ability to foster lateral thinking—a key element in creativity [72,75]. In balanced exploration, StickyNexus favored pattern E in early stages and pattern F during convergence, leveraging its flexibility to integrate lateral and vertical idea development. In comparison, the baseline system fewer balanced exploration patterns, underscoring its limitations in supporting flexible interactions.

In summary, StickyNexus demonstrated a strong capability to support flexible design thinking by enabling smooth transitions between global and local perspectives. This flexibility helps designers uncover meaningful relationships among ideas. These findings align with recent studies on nonlinear collaboration with LLMs [76].

7.2 Supporting Complex Information Management in Diverse Design Tasks. Our study aims to leverage the interactive advantages of sticky notes to enhance the effectiveness of AI-assisted design. On the one hand, our methods ensures that the information management process aligns with designers' cognitive workflows and helps designers more clearly interpret AI-generated suggestions. On the other hand, it also enables AI to better understand designers' thought processes, allowing for more targeted and meaningful suggestions.

Regarding the potential application space, STICKYNEXUS is not designed for a specific type of design task. Instead, it is applicable across a wide range of design scenarios that require information organization to support idea clarification. For example, Fig. 8 demonstrates how STICKYNEXUS assists in the structural and functional design of a robotic arm. In addition, STICKYNEXUS can support tasks such as appearance design, material selection based on user preferences, and sustainability assessment in terms of product energy consumption. It can also aid multiple stakeholders in forming a unified understanding and optimize the collaboration in manufacturing process.

Additionally, STICKYNEXUS has the potential to integrate with computer-aided design (CAD) and computer-aided engineering (CAE) software as a plugin, enhancing designers' abilities to mine multimodal design information effectively. Current CAD and CAE software have already begun integrating AI-assisted capabilities. For instance, MAYA,[12] allows designers to manipulate scenes using natural language text prompts, such as adjusting object size, duplicating elements, or setting camera angles. This simplifies operation steps and optimizes workflows. Specifically, STICKYNEXUS could integrate with CAD/CAE tools like SOLIDWORKS[13] by helping designers systematically plan model creation steps through organized sticky note clusters and identifying key structural requirements by interpreting relationships and design concepts visually. Furthermore, integration with node editors such as BLENDER[14] could leverage STICKYNEXUS' capability to visually map idea exploration and recombination, simplifying complex node relationship.

8 Limitations

Our work has the following limitations, which can be addressed in future work. First, each experimental task lasted only 30 min to reduce user fatigue. The session of 60-min would be ideal, providing designers with more time to explore various approaches to managing information. Longer interactions could also lead to new insights. Second, we only utilized basic inherent properties of sticky notes, like position, movement, and content. As real-time video analysis technology advances, analyzing more advanced elements may become possible—for example, graphical interactions (clicking, dragging, modifying) and time-series analysis of iterations (the evolution of sticky notes over time). We could also integrate more multimodal large models to enhance information extraction, transformation, and historical access.

9 Conclusion

In this work, we introduced STICKYNEXUS, a flexible sticky note system supported by LLM, designed to enhance information management and creative idea exploration from both global and local perspectives. By enabling designers to freely switch between different perspectives, STICKYNEXUS facilitates the discovery of new possibilities and connections within information. STICKYNEXUS's global view supports the exploration of clustered relationships, fostering effective communication with the LLM and the synthesis comprehensive design solutions. Our user study showed that STICKYNEXUS's visual management significantly supported designers' creativity and facilitated both lateral and vertical transformations of their ideas. Overall, our work offers a practical reference for using LLMs to support flexible exploration and complex information management.

Funding Data

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Conflicts of Interest

There are no conflicts of interest.

Data Availability Statement

The authors attest that all data for this study are included in the paper.

Appendix A: Baseline

The interface and use case of JAMBOT are shown in Fig. 12. There are five functions in baseline frequently used by participants. (1) Ideate. It can inspire various team-building ideas. (2) Quick question. It allows participants to ask questions. (3) Give me. It provides information about specific topics. (4) Rabbit hole. It helps participants explore deep details of a topic. (5) Summarize. It can summarize long notes or documents into a brief overview.

[12]https://www.autodesk.com/products/maya/overview
[13]https://www.solidworks.com
[14]https://www.blender.org

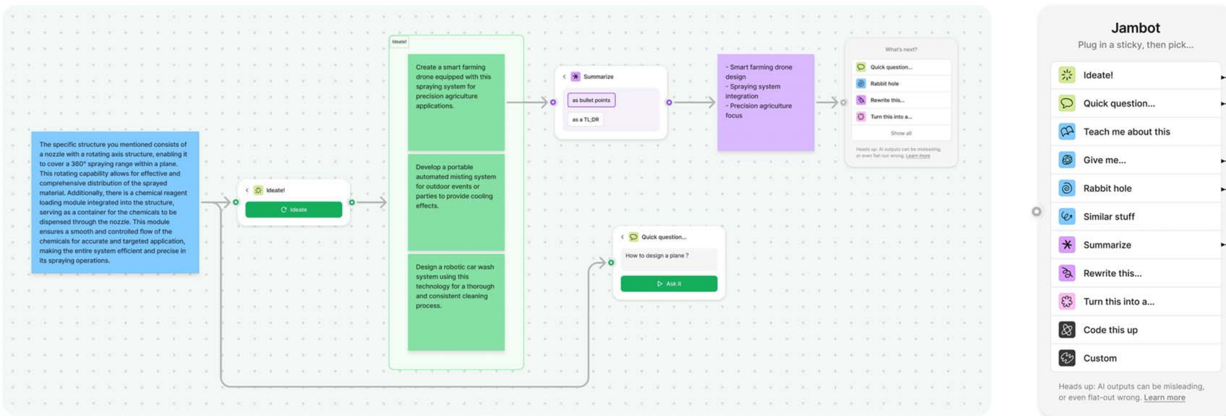

Fig. 12 The interface and use case of JAMBOT in the user study

Appendix B: The Coding Results of Participants' Design Process

To reveal feature impacts, we coded transformations of sticky note content, sources of contributions, and the use of global or local strategies. The results are shown in Fig. 13.

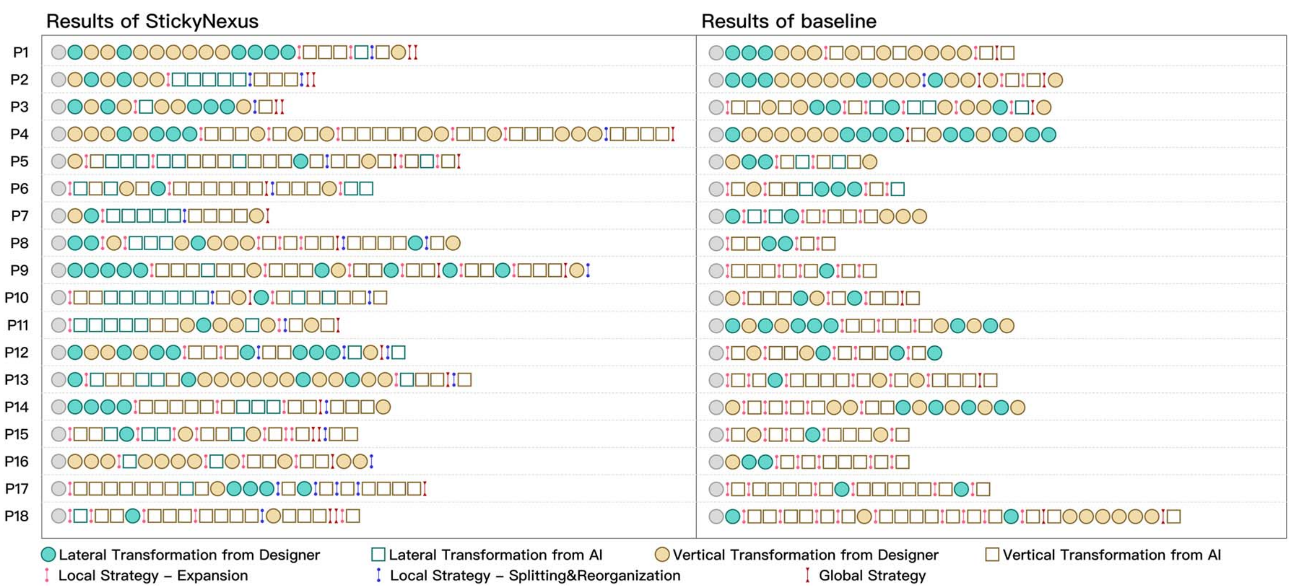

Fig. 13 Coding results of designers' vertical and lateral design thinking transformations and system usage during the experiment process

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