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VISUAL LINK ANALYSIS OF SKETCHING AS A COMMUNICATION TOOL IN THE CONCEPTUAL PHASE OF AUTOMOTIVE DESIGN

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Abstract:

This study investigates the communicative role of sketching during the conceptual phase of automotive design by analyzing visual link structures produced under different interaction conditions. Eighteen automotive designers, divided into silent (non-verbal) and verbal (spoken) teams, participated in structured sketching tasks comprising individual and collaborative phases. A total of 59 sketching moves that directly contributed to the final design were identified and linked through visual connections, classified as either lateral (divergent) or vertical (refinement). Results reveal that silent groups produced more vertical links during the individual stage (n = 7) compared to verbal groups (n = 4), suggesting that sketching was used as a self-contained communication tool to externalize and clarify design intent. In the collaborative phase, both group types exclusively generated vertical links (n = 15 each), indicating a shared focus on refinement. Visual link maps and annotated sketch sequences demonstrate how silent teams constructed coherent visual narratives across phases, while verbal teams relied more heavily on spoken dialogue to guide refinement. These findings support the use of sketching as a flexible communication modality and establish visual link

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analysis as a valuable method for studying design behavior in collaborative contexts.

Keywords:

Sketching, Communication, Automotive Design, Conceptual Phase, Visual Link Analysis, Team Collaboration

Introduction

Effective communication during the conceptual phase of automotive design is essential for aligning team perspectives, navigating ambiguity, and progressing from divergent ideas to cohesive solutions. While sketching is widely recognized as a fundamental practice in early-stage design, its role as a communication tool across different modes of interaction has remained underexplored. Designers often use sketches not only to externalize individual ideas but also to support negotiation and facilitate shared understanding (Härkki, 2023; Van der Lugt, 2005). However, the communicative dynamics of sketching can vary significantly depending on whether teams engage in verbal dialogue or work in silence (Ariff, 2020).

In collaborative design environments, particularly in automotive contexts where complexity and multidisciplinary collaboration are common, sketching frequently serves beyond its representational function (Ariff & Badke-Schaub, 2011). It becomes a bridge for negotiating meaning, coordinating design decisions, and clarifying intent (Chandrasegaran, Ramanujan, & Elmqvist, 2018). While previous research has emphasized the cognitive and ideational functions of sketching, such as problem-solving and creative exploration (Abidin, Sigurjonsson, Liem, & Keitsch, 2008; Goldschmidt, 1991; Tversky, 2013), fewer studies have examined its communicative role across different team interaction modes. Most analyses rely on verbal protocol data or focus solely on final design outputs, without systematically tracing how sketches evolve over time and convey intent within collaborative workflows (Chandrasegaran et al., 2017; Omar et al., 2022; Shi, Gao, Jiao, & Cao, 2023)

To address this gap, the present study applies visual link analysis as a methodological lens to investigate how sketches are used as communicative tools in both silent and verbal design teams. Visual link analysis captures the structural relationships between sketches by distinguishing lateral links, which represent divergent exploration, from vertical links, which indicate progressive refinement. This approach enables an empirical understanding of how design ideas are constructed, negotiated, and aligned visually.

Accordingly, this study seeks to answer the following research question: **How do visual link structures reflect the communicative role of sketching during the conceptual phase of automotive design?**

By comparing silent and verbal groups across both the ideation and collaboration stages, the study demonstrates how sketching facilitates team alignment in different interaction contexts and establishes visual link analysis as a promising method for understanding the dynamics of design communication beyond spoken language.

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Literature Review

Sketching plays a central role in the early stages of design by enabling the externalization of ideas, supporting exploration, and serving as a medium for communication (Goldschmidt, 1991; Rahim, Ariff, Yusof, & Badke-Schaub, 2024). In the context of team-based design, sketching also helps in aligning mental models and negotiating meaning (Ariff, Eris, & Badke-Schaub, 2013; Yang & Min, 2025). These communicative aspects become especially important during the conceptual phase, where ambiguity is high and shared understanding is still forming.

Several studies have highlighted the multimodal nature of design communication, where sketching complements or substitutes verbal explanation (Ariff, Badke-Schaub, & Eris, 2012; Pattiasina, Lamaloang, & Santoso, 2025). In silent settings, sketches must encode sufficient meaning to be understood without speech, whereas in verbal settings, sketches often operate in tandem with dialogue to support co-construction. However, most prior work either analyzes verbal interaction through protocol analysis or studies sketches as static outputs, without investigating the structural progression of visual ideas.

Visual link analysis builds on the principles of linkography (Goldschmidt, 2016) extending it into a visual domain by tracing how sketches relate to one another over time and across participants. This method allows researchers to examine how design ideas evolve through lateral expansion, which introduces new directions, or vertical refinement, which builds upon earlier work. It provides insight into how teams construct and communicate meaning through visual means. While linkography has been applied to assess creativity or problem-solving, its use as a diagnostic tool for communicative function in sketching remains limited.

This study builds on these foundations by using visual link analysis to investigate how sketching facilitates communication in silent and verbal automotive design teams. It aims to bridge the gap between sketching as a visual thinking tool and sketching as a shared visual language, particularly under varying communication conditions.

Method

This study employed a quasi-experimental, comparative design to investigate how sketching functions as a communication tool under different interaction conditions: silent (non-verbal) versus verbal. The objective was to analyze not only the content of the sketches but also the structural progression of ideas over time, thereby uncovering how sketching supports shared understanding and design refinement within teams.

The study adopted a mixed-methods approach, combining qualitative analysis (through interpretive coding of visual sketch features and communicative patterns) and quantitative elements (such as link counts and distributions across phases and teams). This design allowed a comprehensive understanding of both the nuanced visual development of ideas and measurable differences between communication settings.

Participants and Design Task

A total of 18 Malaysian automotive designers participated in the study. Participants were recruited based on their educational background or professional experience in transportation design, ensuring a baseline level of design fluency. They were grouped into six teams (three per condition), with each team consisting of three members. Teams were randomly assigned to one of two communication modes:

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- Silent condition (n = 3 teams): No verbal communication was permitted throughout the design session.
- Verbal condition (n = 3 teams): Teams were allowed to discuss their ideas freely using spoken language.

All teams were given the same design brief, which asked them to conceptualize a personal mobility vehicle accessible for wheelchair users. The design task was structured in two sequential phases:

1. Individual Stage (Phase 1): Each participant independently sketched initial concepts without team interaction.
2. Collaborative Stage (Phase 2): Team members reconvened to discuss and integrate their ideas into a final shared sketch.

Sessions were conducted in a controlled environment, video-recorded for cross-referencing, and all sketches were collected at the end of each stage for systematic analysis.

To visualize the research flow, Figure 1 presents the overall experimental setup, including group structure, task stages, and interaction modalities. Each group consisted of three participants. All teams followed the same workflow: a 20-minute individual idea generation phase, followed by a 5-minute break and a 50-minute collaborative idea finalization session. Silent groups completed both phases without verbal interaction, relying solely on visual sketching, while verbal groups were allowed to communicate verbally.

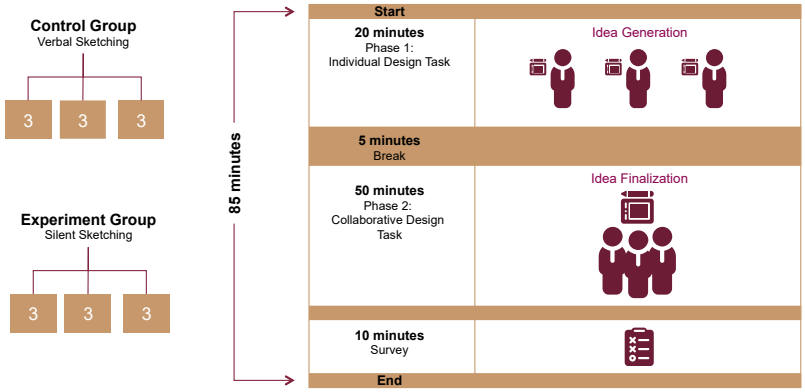

Figure 1. Experimental Procedure For Silent And Verbal Sketching Groups Across Two Stages: Individual Idea Generation And Collaborative Idea Finalization.

Figure 2 presents the overall research process, from participant recruitment through data analysis. This flowchart clarifies the sequence and integration of qualitative and quantitative components across the study.

Figure 2. Research Process Flowchart.

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Data Sources and Management

Two primary data sources were used in this study:

1. Sketch artifacts, produced during both individual and collaborative phases.
2. Video recordings of each session, used to track sketch timing and to validate visual link decisions.

All sketches were scanned and digitally archived. Each sketching move was coded with metadata including group ID, participant ID, design phase, and move ID. Time-stamped video recordings were used to cross-reference the chronological order of moves and ensure accurate segmentation and analysis. Data files were organized in a secure digital repository, following consistent naming conventions to facilitate traceability.

Data Collection and Move Segmentation

Data collection focused on analyzing the progression of sketches produced across the two-stage design protocol. The study employed visual link analysis, adapted from traditional linkography (Goldschmidt, 2016), to trace how sketch moves interrelate and evolve, revealing the visual structure of idea development and team alignment.

Unlike conventional linkography based on verbal transcripts, visual link analysis emphasizes non-verbal artifacts such as sketches, annotations, and refinements as communicative tools. Recent innovations such as gaze-integrated linkography (Härkki et al., 2023) and fuzzy link-mapping for ill-defined problems (Smith et al., 2025) reinforce the method's value for understanding visual design cognition.

All sketches were scanned and digitally archived. Each sketching move was coded with metadata including group ID, participant ID, design phase, and move ID. Time-stamped video recordings were used to cross-reference the chronological order of moves and ensure accurate segmentation and analysis. Data files were organized in a secure digital repository, following consistent naming conventions to facilitate traceability.

1. **Category of Design Intent**
   - Form*:* stylistic and aesthetic aspects (e.g., proportions, silhouette, line quality)
   - Function: usability and technical intentions (e.g., accessibility, structure)
   - Form and Function: contributions addressing both aesthetics and usability
2. **Participant ID**
   - Each move was associated with the designer who produced it during the individual phase and left anonymous in the collaborative phase.
3. **Design Stage**
   - Individual*:* initial ideation
   - Collaborative*:* synthesis and refinement

Each move was then analyzed for its visual connection to earlier moves, forming a structured map of design progression and team communication.

Table 1 illustrates how design ideas evolved within Silent Group 2 (SG2) by mapping visual links across sketching moves. It shows how individual contributions, such as early sketches for lowered ground clearance (SG2-M1) or rounded vehicle forms (SG2-M5), were visually

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developed through linked refinements that culminated in a final collaborative solution (SG2-M11). Vertical links in the table represent iterative deepening of ideas, while lateral links reflect conceptual exploration. This level of mapping offers detailed insight into how sketching, even without verbal interaction, enabled the team to communicate, refine, and align their design thinking.

Table 1: Attributes Of Visual Links Taken From Silent Group 2

Group	Stage	Move ID	Category	Participant	Description of Move	Type of Link	Linked to Move(s)
G2 Silent	**Individual Stage**	SG2-M1	Form	P4	Practical aesthetic with lowered ground clearance	Lateral	-
		SG2-M2	Form and Function	P4	Large door opening for easy wheelchair access	Vertical	SG2-M1
		SG2-M3	Form	P5	Friendly and practical silhouette design	Lateral	-
		SG2-M4	Function	P5	Rear accessibility optimized for ingress and egress	Vertical	SG2-M3
		SG2-M5	Form	P6	Rounded, continuous single-form structure	Lateral	-
		SG2-M6	Form	P6	Evolving into a three-wheeler with rounded proportions	Vertical	SG2-M5
	Collabora-tive Stage	SG2-M7	Form	-	Adjusting front tire proportions for balance with lower profile	Vertical	SG2-M1, SG2-M6
		SG2-M8	Form	-	Finalizing proportions of the three-wheeled car design	Vertical	SG2-M7
		SG2-M9	Form	-	Refinement of overall silhouette	Vertical	SG2-M6, SG2-M8
		SG2-M10	Function	-	Finalizing rear door for practical accessibility	Vertical	SG2-M2, SG2-M4, SG2-M9
		SG2-M11	Form and Function	-	Comprehensive final sketch with detailed enhancements	Vertical	SG2-M10

Visual Link Analysis: Procedure and Technique

To systematically evaluate how sketching supported communication and idea development, each sketch move was analyzed for its visual linkage to preceding moves. This process enabled the reconstruction of design trajectories across both individual and collaborative phases, revealing how ideas were visually extended, refined, or transformed within teams.

The primary analytical approach was visual link analysis, adapted from traditional linkography (Goldschmidt, 2016), and customized to prioritize sketch-based, non-verbal communication. This method allowed the study to trace how design ideas progressed visually, offering empirical insight into team cognition, alignment, and communication strategies.

Two primary link types were identified:

- Lateral links, which represent divergence-such as exploring alternative directions or proposing parallel ideas.
- Vertical links, which represent refinement-indicating development or elaboration of existing concepts.

The identification of links was based on a multi-criteria assessment:

- Visual similarity in form or functional intention,
- Continuity of sketch features (e.g., geometry, structure),

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- Sequential positioning and timing of moves within each design session, and
- Sketch annotations or modifications that signaled idea evolution.

To ensure consistency, link decisions were cross-validated with time-stamped video recordings of each design session. This triangulation process helped verify both the temporal sequencing and conceptual continuity of the moves, ensuring robust interpretation beyond surface-level visual similarity.

The resulting dataset was then used to generate visual link maps, which allowed for network-based visualization of sketching behaviors and quantitative comparison of sketching structures across silent and verbal teams. Crucially, only sketching moves and links that directly contributed to the final collaborative design solution were included in the analysis; exploratory or discarded trajectories were excluded. These visual link structures provide empirical evidence of how teams communicated, negotiated, and converged through sketching alone, particularly in the absence of verbal dialogue.

Findings

This section presents the findings of the visual link analysis applied to sketching data from six automotive design teams, comparing silent and verbal communication conditions. Each sketching move was categorized by link type as either lateral, representing divergent exploration, or vertical, indicating refinement, and then mapped according to its occurrence in the individual or collaborative phase. The analysis revealed clear differences in sketching patterns and communicative behavior between the two conditions.

Link Distribution by Group and Phase

A total of 59 visual links were identified across all design teams, classified into two types: lateral links, which represent divergent exploration, and vertical links, which reflect refinement or progressive development. These links were analyzed across two dimensions: communication mode (silent versus verbal) and design phase (individual versus collaborative), to examine how different interaction settings influenced the development of ideas through sketching. A numerical summary is presented in Table 2. Link counts in this table include only those moves and connections that contribute directly to the final collaborative sketch.

Table 2: Link Distribution Across Stages And Communication Modes

Stage	Group Type	Lateral Links	Vertical Links
Individual	Silent	9	7
Individual	Verbal	9	4
Collaborative	Silent	0	15
Collaborative	Verbal	0	15

As shown in Table 2, during the individual phase, both silent and verbal groups generated the same number of lateral links (n = 9), suggesting that verbal interaction was not essential for early-stage ideation. Participants working in silence demonstrated an equivalent breadth of conceptual exploration, challenging the assumption that verbal dialogue inherently enhances divergent thinking.

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However, a key difference emerged in vertical link production, where silent teams recorded nearly twice as many refinement links (n = 7) compared to verbal teams (n = 4). This suggests a stronger reliance on self-guided visual iteration in the absence of verbal cues. In this context, sketching functioned not only as a tool for generating ideas but also as a means of refinement, underscoring its role as a communicative mechanism in the absence of speech.

In the collaborative phase, all groups produced only vertical links (n = 15 per group type), indicating a uniform shift toward convergence and finalization. The complete absence of lateral links reflects a transition from exploration to synthesis, as teams integrated individual ideas into coherent design solutions.

Figure 3 visually compares these distributions, highlighting sketching's adaptive role across different interaction modes.

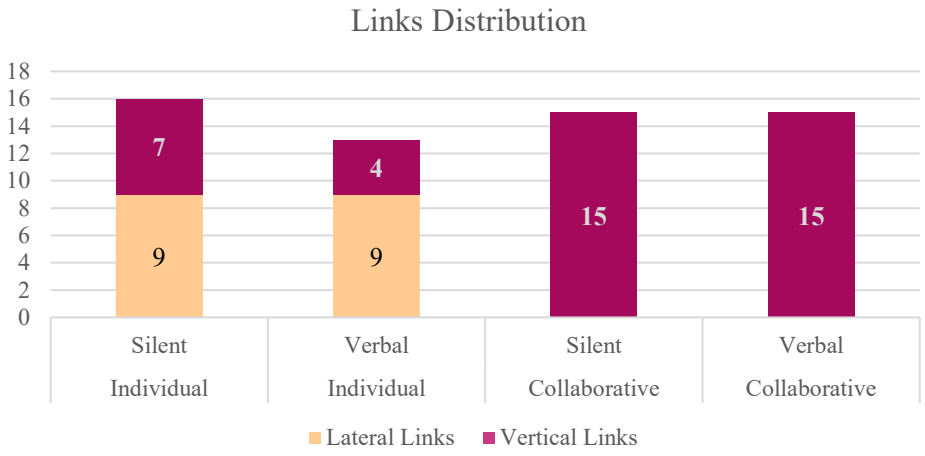

Figure 3. Distribution Of Visual Links Across Group Types And Design Phases

This distribution pattern reinforces the dual communicative function of sketching, supporting both divergence and convergence. In the individual phase, the presence of lateral links across both group underscores sketching's foundational role in exploring design alternatives, regardless of communication mode. The increased vertical linking in silent teams further reveals that, when speech is absent, designers depend more heavily on sketch-based refinement to evolve their ideas.

To determine whether the observed difference in vertical link frequency between silent and verbal groups during the individual phase was statistically significant, a chi-square test of independence was conducted. The result, χ^2 (1, N = 29) = 0.62, p = 0.43, indicates that the difference was not statistically significant. Although silent teams showed a higher number of vertical links, this variation likely reflects differences in design strategy rather than a systematic effect of communication mode.

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In contrast, the collaborative phase exhibited a consistent focus on vertical linking, with all teams, regardless of communication condition, engaging in convergent refinement. This underscores sketching's broader role as a structured visual medium for team coordination, alignment, and decision-making across both verbal and non-verbal design settings.

Visual Link Analysis: Silent Group 2 as a Case of Non-Verbal Design Convergence

This section presents an in-depth visual link analysis of Silent Group 2 (SG2) to illustrate how sketching alone can support both idea development and team alignment in the absence of verbal communication. Rather than attempting to generalize across all silent teams, this focused case highlights the mechanics of visual reasoning and refinement in a purely non-verbal design environment. Vertical links—used here as indicators of progressive elaboration—trace how design intent is shared, interpreted, and incrementally developed through sketching alone.

The sketch trajectory of SG2 reflects a coherent visual dialogue that transitioned seamlessly from individual ideation to collaborative convergence. In the individual phase, each participant introduced unique concepts grounded in accessibility and aesthetics. These early moves, such as SG2-M1 (low ground clearance form), SG2-M3 (friendly silhouette), and SG2-M5 (rounded continuous body), established foundational ideas through lateral links. Importantly, these were not isolated gestures; vertical links such as SG2-M2, SG2-M4, and SG2-M6 demonstrate immediate efforts toward self-refinement within individuals' visual space, forming a scaffold for later collective decisions.

Figure 4 visualizes this evolution, from initial ideation in SG2-M1 to final resolution in SG2-M11, capturing the layered progression of form-function integration achieved entirely through drawing.

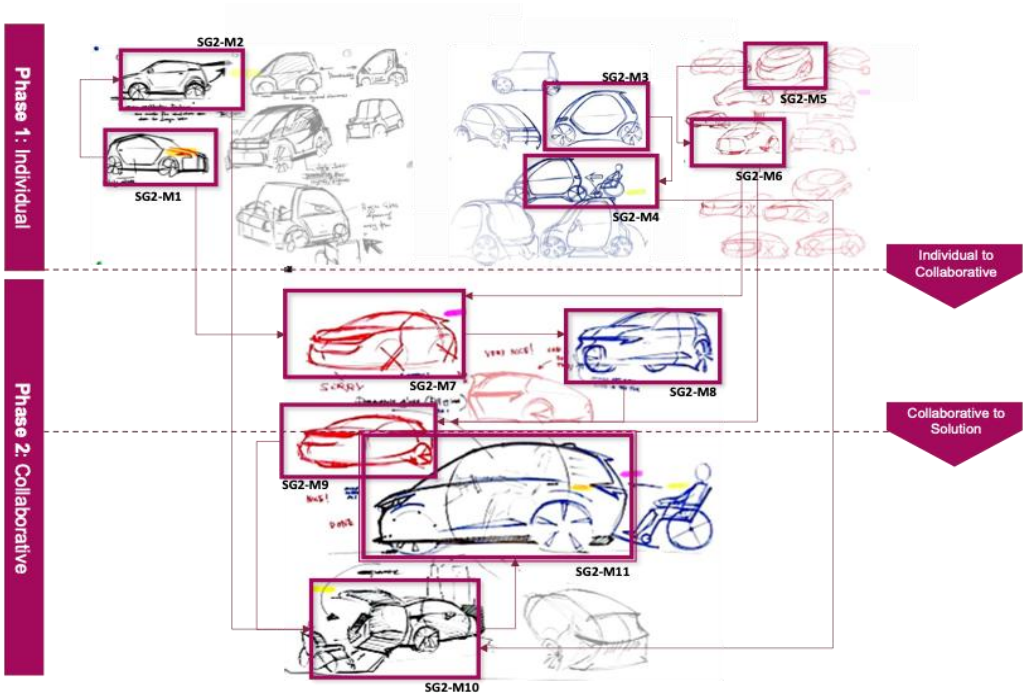

Figure 4. Sketch Evolution Of Silent Group 2 (SG2) From Individual To Collaborative Phases.

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As the team transitioned to the collaborative phase, sketches like SG2-M7, SG2-M8, and SG2-M9 did not introduce new visual directions but built directly upon earlier forms. This pattern of vertical linkage reflects mutual recognition and shared understanding among team members, achieved entirely through visual interpretation. The absence of lateral links during collaboration suggests that once individual concepts had been externalized, the team prioritized alignment and synthesis over further exploration.

Key refinement sequences include:

- SG2-M1 → SG2-M2: A grounded, practical form is elaborated into a more inclusive layout via a wide-access door, showing functional layering without altering the core form.
- SG2-M5 → SG2-M6 → SG2-M7 → SG2-M9: An aesthetic theme centered on rounded geometry progresses into a stable three-wheeled form through iterative structural tuning.
- SG2-M10 → SG2-M11: Critical accessibility considerations at the rear are finalized in a comprehensive sketch that merges ergonomic detailing with visual consistency.

This deep vertical progression reveals that sketching in SG2 served as more than just a design activity; it functioned as a shared cognitive system. Each visual move encoded intention and enabled interpretation, acting as a surrogate for spoken agreement. The collective shift from ideation to refinement occurred entirely through visual feedback, confirming sketching's capacity to mediate design reasoning and team alignment under silent conditions.

To further explore how vertical links facilitated alignment in silent collaboration, Move SG2-M10 from the collaborative stage is analyzed in detail. This sketch represents a pivotal functional refinement focused on rear accessibility.

Table 3. Linked Moves In Collaborative Stage For SG2-M10

Stage	Move ID	Category	Linked to Move(s)	Type of Link
Collaborative	SG2-M10	Function	SG2-M2, SG2-M4, SG2-M9	Vertical

SG2-M10 was built upon three prior moves:

- **SG2-M2** (*Form and Function*): Introduced a large entry opening for easy wheelchair access, establishing the initial idea.
- **SG2-M4** (*Function*): Optimized rear access, refining the ergonomic layout for practical ingress/egress.
- **SG2-M9** (*Form*): Refined the overall silhouette, ensuring that accessibility features harmonized with the visual form.

As a vertical link, SG2-M10 did not introduce a new idea but synthesized and enhanced prior concepts. This move demonstrates the group's use of sketching as a non-verbal iterative tool, where successive refinements led to a coherent, functionally viable solution. The integration of both form and function without verbal dialogue highlights the communicative power of sketching in achieving alignment within the team.

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Figure 5 visually maps this design evolution, illustrating how multiple earlier sketches were systematically referenced and synthesized to finalize the rear-access configuration, balancing accessibility requirements with overall form coherence.

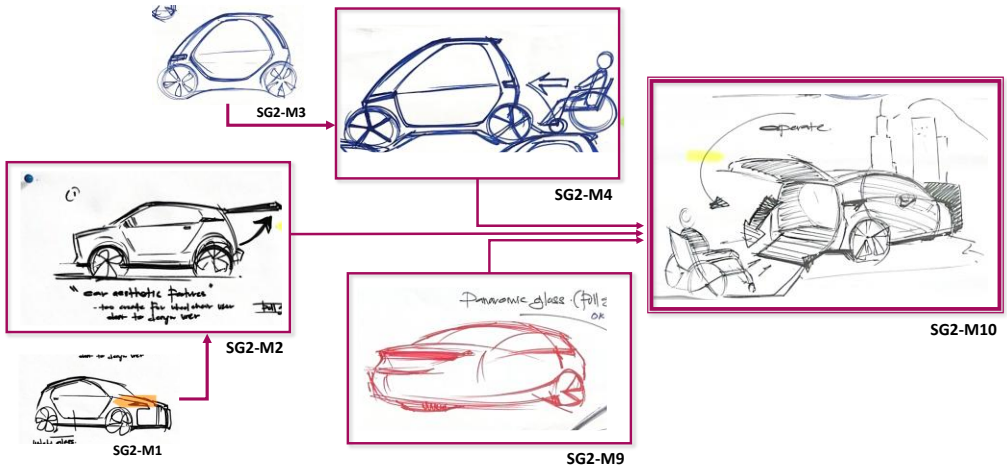

Figure 5. Evolution Of Rear Door Design Through Vertical Links (Silent Group 2)

SG2 is selected as a strategic case based on single-case logic, offering a clear, traceable example of non-verbal design convergence. Its dense vertical links and visual coherence reveal how sketching alone supported both individual refinement and team alignment. Drawing functioned as an external memory scaffold, allowing designers to interpret, extend, and converge ideas silently. This case illustrates how shared understanding can emerge through purely visual interaction.

Communicative Structures in Silent vs. Verbal Sketching

The contrast between silent and verbal groups indicates two distinct modes of sketch-based communication:

- Silent teams used sketching as a complete communication system, enabling them to iterate, refine, and align ideas without verbal reinforcement.
- Verbal teams used sketching as a visual support to verbal communication, often treating sketches as references rather than primary communicative tools.

These patterns are visualized in Figure 6, which compares link depth and density across group types. Despite similar final move counts (SG2-M11, VG1-M9), silent teams demonstrated more coherent sketch trajectories driven by visual refinement, while verbal teams relied more heavily on dialogue to achieve convergence.

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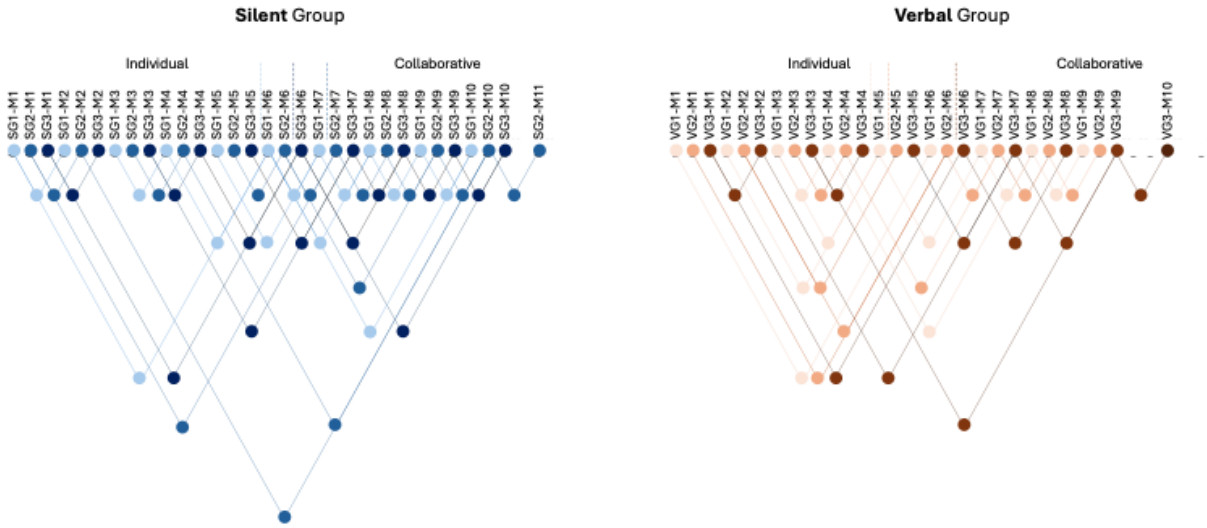

Figure 6. Comparative Visual Link Maps For Silent Vs. Verbal Sketching Groups (Individual And Collaborative Stages)

Figure 6 presents the cumulative visual link structures from all silent (left) and verbal (right) groups. Each dot corresponds to a sketching move arranged sequentially from left (individual) to right (collaborative), with connecting lines denoting either lateral or vertical links. Two critical differences emerge:

1. **Intra-individual refinement in Silent groups**: The left plot reveals a deeper and denser concentration of links during the individual phase, particularly in SG1 and SG2. Multiple vertical links exist between early individual moves (e.g., SG1-M1 → SG1-M2, SG2-M1 → SG2-M2), indicating self-refinement even before team convergence. This implies that sketching served as an autonomous tool for evolving ideas, fulfilling both expressive and interpretive functions without speech.
2. **Collaborative dependency in Verbal groups**: The right plot shows a more delayed onset of vertical integration. While lateral moves exist early, vertical refinement occurs predominantly during collaboration (e.g., VG2-M5 → VG2-M9). This suggests that verbal interaction drove convergence, with sketches playing a more confirmatory or supportive role.

These structural differences highlight how sketching affords distinct communicative functions across interaction modes. Silent teams relied on iterative visual construction to build shared understanding, whereas verbal teams used sketches primarily to document verbally negotiated decisions. The greater link density and coherence in silent groups indicate stronger visual interdependence, while verbal teams exhibited dependence on spoken dialogue to scaffold their design progression.

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Visual Link Network Metrics

To complement the qualitative analysis of sketch progression, Table 4 presents a summary of quantitative visual link metrics derived from the final sketching trajectories.

Table 4. Summary Of Link Metrics By Communication Mode

Metric	Silent Group	Verbal Group
Total Moves / Links	31	28
Lateral Links (Individual Stage)	9	9
Vertical Links (Individual Stage)	7	4
Vertical Links (Collaborative Stage)	15	15
% of Moves with ≥2 Incoming Links	35.48%	21.43%
Max Link Depth (Longest Refinement)	9	7

The total number of sketching moves and visual links was 31 for the silent groups and 28 for the verbal groups. These figures include only the contributions that directly informed the final collaborative design solution, with exploratory or discarded sketches excluded from the analysis. Both communication modes produced an equal number of lateral links during the individual phase (n = 9), indicating that early-stage divergent thinking was not dependent on verbal interaction. However, the silent teams produced more vertical links in the individual phase (n = 7), compared to the verbal teams (n = 4), suggesting a stronger reliance on sketch-based self-refinement.

In the collaborative phase, both group types demonstrated an exclusive focus on vertical linking (n = 15), marking a consistent transition toward integration and convergence. Notably, 35.48% of moves in the silent group received two or more incoming links, compared to 21.43% in the verbal group. This indicates a higher degree of visual integration in silent teams, where participants more frequently referenced multiple earlier sketches to build shared meaning. The maximum refinement depth, defined as the longest uninterrupted sequence of visual links culminating in the final design move, was greater in the silent condition, with a depth of nine links, compared to seven links in the verbal condition. These differences underscore the role of sketching as a robust communicative medium in silent settings, where the absence of speech is compensated by deeper, more recursive visual reasoning.

Summary of Key Findings

To consolidate the insights from the visual link analysis, Table 5 presents a comparative summary of sketching behaviors across silent and verbal groups. This synthesis highlights how both communication modes shaped idea generation, refinement, and team alignment through visual means.

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Table 5. Summary Of Main Findings From Visual Link Analysis

Aspect Analyzed	Silent Groups	Verbal Groups	Key Insight
Lateral Links (Individual Phase)	9	9	Equal breadth in early-stage idea exploration
Vertical Links (Individual Phase)	7	4	Silent teams relied more on sketch-based refinement
Vertical Links (Collaborative Phase)	15	15	All teams converged through refinement during collaboration
Multiple Incoming Links (% of Moves)	35.48%	21.43%	Silent teams more frequently integrated multiple ideas
Max Link Depth (Refinement Chains)	9 links	7 links	Silent teams showed deeper visual development trajectories
Sketch Role in Communication	Primary mode of communication	Co-primary mode alongside verbal talk	Sketches supported shared understanding in both conditions

The visual link analysis revealed both commonalities and distinctions in how silent and verbal automotive design teams used sketching as a communication tool. During the individual phase, both groups produced an equal number of lateral links (n = 9), indicating comparable divergent exploration regardless of communication mode. However, silent teams generated more vertical links (n = 7 vs. 4), suggesting greater reliance on self-guided visual refinement. In the collaborative phase, all groups produced only vertical links (n = 15), reflecting a shared focus on convergence. Silent groups exhibited deeper visual integration, with 35.48% of their moves referencing multiple prior sketches, compared to 21.43% in verbal groups. Although verbal teams engaged in spoken dialogue, they also used sketches as a primary channel to build shared understanding, reinforcing the communicative power of drawing in both verbal and non-verbal design settings.

Discussion

This study set out to investigate how sketching functions as a communicative mechanism under different interaction conditions, specifically in silent (non-verbal) and verbal (spoken) automotive design teams. The findings, interpreted through visual link analysis, reveal important differences in how sketches were used to support ideation, refinement, and team alignment.

Sketching as a Communication Modality

The results demonstrate that sketching can function as a complete communication system in the absence of verbal interaction. Silent teams consistently produced structured sequences of vertical links, especially during the collaborative phase, indicating that sketching was actively used to negotiate meaning, refine ideas, and align design intent. This supports the notion that visual artifacts carry embedded communicative intent, which team members can interpret and build upon, thereby highlighting drawing as a form of visual dialogue (Goldschmidt, 2016; Nik Ahmad Ariff, Badke-Schaub, Eris, & Suib, 2012; Tversky, 2013).

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In contrast, verbal teams generated fewer vertical links during the individual stage and showed a delayed onset of refinement until collaborative discussions began. Sketching in these teams often served a supporting role, formalizing decisions already reached through speech. This distinction underscores the dual role of sketching: in silent settings, it is a primary communicative medium; in verbal contexts, it becomes a confirmatory or illustrative tool.

Structural Patterns and Cognitive Implications

Quantitatively, silent teams exhibited a greater number of multi-linked sketches (11 moves with ≥2 incoming links, 35.5%) compared to verbal teams (6 moves, 21.4%). This suggests that silent teams were more reliant on sketching to integrate diverse contributions, leading to denser visual networks that facilitated convergence without speech. The higher maximum link depth in silent teams (9 vs. 7 in verbal teams) further supports the argument that refinement chains in non-verbal settings were longer and more deliberate.

These structural metrics align with the theory of distributed cognition (Choi, Jung, Park, Kim, & Han, 2025; Hollan, Hutchins, & Kirsh, 2000), where external representations such as sketches, serve as shared memory and reasoning tools. In silent teams, the sketch board became a collective cognitive workspace, enabling participants to iteratively reinterpret and extend each other's ideas. Verbal teams, by contrast, offloaded much of this negotiation to dialogue, which may not be traceable in visual artifacts alone.

Implications for Design Practice

From a practical standpoint, these findings have implications for how design teams might structure their communication workflows. In situations where verbal communication is limited, such as during remote collaboration, in the presence of language barriers, or in early-stage ideation, drawing can serve as a robust substitute for verbal negotiation. Facilitating sketch-based iteration may also reduce over-reliance on discussion, encouraging deeper engagement with visual reasoning and spatial thinking.

Moreover, the visual link metrics offer a diagnostic tool for evaluating team dynamics. High link density and refinement depth may indicate effective internalization and alignment, while sparse or fragmented link structures could signal misalignment or shallow engagement. These indicators can inform coaching, evaluation, and team composition decisions in design education and professional practice.

Limitations and Future Work

While this study offers structured evidence of sketching as a communicative modality under varying interaction conditions, several limitations should be acknowledged. First, the analysis was restricted to final-contributing sketching moves, potentially underrepresenting exploratory or discarded ideas that are crucial in creative processes (Goldschmidt, 1995; Jackson, 2025). Second, although the link structures offer strong visual indicators of refinement and alignment, they do not capture non-verbal cues such as gestures or eye gaze that may supplement communication. These elements are often emphasized in multimodal studies of design teams (Lee et al., 2020). Furthermore, the short-term, task-focused nature of the sessions contrasts with the longitudinal and iterative dynamics observed in real-world design practice (Van der Lugt, 2005). Future research should extend this visual link methodology to multimodal analysis, incorporating temporal, spatial, and embodied cues. Comparative studies across

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different cultural or disciplinary contexts may also yield broader insights into how sketching mediates collaborative cognition.

Conclusion

This study examined how sketching functions as a communication tool during the conceptual phase of automotive design under silent and verbal interaction conditions. The research objectives were achieved through visual link analysis, which revealed that sketching supported the externalization, refinement, and alignment of ideas in both settings. Silent teams demonstrated a stronger reliance on visual reasoning, producing deeper refinement structures without verbal input, while verbal teams used sketches to reinforce shared understanding alongside dialogue. Despite these contributions, the study is limited by its small, culturally specific sample of Malaysian designers, and by the inherent constraints of visual link analysis, which cannot fully capture internal cognitive processes. The findings have implications for both design education and professional practice, suggesting that silent sketching sessions can foster deeper visual thinking, while sketches may serve as a common visual language in multidisciplinary or linguistically diverse teams. Future research should include more diverse participant groups, explore hybrid modes of communication, and investigate sketching within digital platforms. Further development of the method could incorporate gesture-based observations such as pointing or tracing to better understand non-verbal interactions. These directions will strengthen our understanding of sketching as a flexible and multimodal tool for communication and convergence in collaborative design.

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