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Adaptive Graphic Interaction Model: A Mixed-Method Framework for Future Factory Design

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Abstract*. This study investigates the role of visual interfaces in enhancing human-machine interaction in high-tech factory environments. The research focuses on the Adaptive Graphical Interaction Model (AGIM), which integrates graphic design principles with adaptive visual interactions to support context-sensitive user tasks. A mixed-methods approach was employed: domain specialists were interviewed, and experimental lab tests of prototype interfaces were conducted to measure user experience, cognitive load, and visual usability. Quantitative metrics from UX tools and qualitative coding of observed behavior were used to assess performance under different simulated operating conditions. Results indicate that AGIM reduces cognitive load by 18% on average and improves task efficiency by 12% compared to static interfaces, supporting the practical effectiveness of adaptive visual systems. The findings also suggest that context-sensitive graphical adaptations enhance intuitive navigation and user engagement. Overall, AGIM provides both conceptual guidance for interface design and practical applications for engineers and designers aiming to develop adaptive, context-aware visual systems in industrial settings. The study is framed as an exploratory design investigation, highlighting potential rather than asserting definitive claims.*

Keywords: *Adaptive Visual Interaction, Graphic Design Integration, Ambient Intelligence, User Experience (UX) Optimization, Smart Factory Interface Design*

INTRODUCTION

Ambient Intelligence (AmI) has transformed human interaction with computational systems, emphasizing context awareness, embedded sensors, and unobtrusive technologies that adapt automatically to human actions (Dunne et al., 2022; Hung et al., 2024). In smart factories, cyber-physical systems integrate IoT and AI to optimize efficiency (Ibrahim & Najmi, 2025), yet visual interfaces often prioritize technical function over cognitive clarity and aesthetic quality (Fortoul-Diaz et al., 2023; Mosleuzzaman et al., 2024). This imbalance limits interfaces' ability to respond to user context, emotional cues, and cognitive load, all of which are critical for intuitive interaction. Graphic design principles, including visual hierarchy, composition, and symbolic content, are essential to enhance interpretability and user engagement (Maksymchuk et al., 2024).

Research gap: Despite advances in ambient intelligence and smart manufacturing, the integration of graphic design into industrial interface design remains limited. Most existing studies emphasize algorithmic optimization, control automation, or ergonomic modeling, neglecting visual design considerations (Jeong et al., 2021; Lee et al., 2022). Current interaction models often treat design elements as static, separating adaptive intelligence from visual communication, creating a disconnect between system functionality and user perception (Rosyida et al., 2025; Sperrle et al., 2021). An integrated framework that combines adaptive intelligence

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with visual design principles is needed to create emotionally engaging and context-aware interfaces (Dunne et al., 2022; Scargill et al., 2023).

This study introduces the Adaptive Graphic Interaction Model (AGIM), which integrates graphic design principles with adaptive interaction processes in ambient-intelligent factory environments. The model aims to enhance usability, cognitive efficiency, and affective experience for users in information-rich industrial settings (Babar et al., 2023; Wang & Hu, 2024) AGIM is developed using a mixed-method approach, combining qualitative insights for model building and quantitative testing for empirical validation, providing a data-driven foundation for visual intelligence in industrial interface design. By emphasizing visual communication logic, the model positions graphic design as central to intelligent interaction, rather than merely decorative (Choi et al., 2024; Prasetya et al., 2025).

AGIM operationalizes graphic design principles, such as hierarchy, Gestalt perception, and adaptive visual composition, to dynamically respond to user context and workload. It provides actionable guidance for UX and industrial designers, ensuring interfaces are functional, cognitively efficient, and emotionally engaging. The model bridges the gap between technology and visual design, aligning machine intelligence with human-centered visual interaction. Ultimately, AGIM contributes to both theoretical understanding and practical application in smart factory interface design, offering a framework for visually adaptive and context-aware systems. Research Questions:

1. How can graphic design principles improve usability, cognitive efficiency, and affective experience in smart factory interfaces?
2. To what extent can adaptive visual systems dynamically respond to user context and workload in industrial environments?

These questions guide the development and evaluation of AGIM, ensuring the study addresses both design reasoning and system adaptability. By framing the study in terms of visual communication logic, the research highlights the unique contribution of graphic design in ambient intelligent environments. This approach shifts the focus from purely technical optimization to integrated, human-centered interface design.

LITERATURE REVIEW

A. Purpose and Scope

This review synthesizes key concepts, theories, and evidence underpinning AGIM, covering research from the last decade. The focus is on ambient-intelligence setups, smart-factory visuals, adaptive interfaces, and graphic-design applications in HCI. By analyzing the interactions among design appearance, cognitive processes, and environmental awareness, this review identifies gaps in the application of graphic design principles in adaptive interaction, which AGIM aims to address by integrating visual reasoning into context-aware systems. The synthesis highlights the need for a model that bridges technical adaptivity with visual hierarchy, Gestalt perception, and aesthetic composition in industrial interfaces.

B. Search Strategy and Selection Criteria

Relevant literature was collected from major databases including Scopus, Google Scholar, IEEE Xplore, ACM Digital Library, and CHI/DIS/DRS proceedings, using keywords combining conceptual and technical dimensions (e.g., “adaptive interface,” “ambient intelligence,” “graphic design + interaction,” “visual hierarchy + UX”). Only peer-reviewed articles, full conference papers, and theoretical monographs (2010–2025) were included, while purely aesthetic explorations without interactive or adaptive features were excluded. This approach provides a cross-disciplinary foundation linking computer science, cognitive psychology, and design studies, highlighting how adaptive systems can embed graphic-visual intelligence into UX design. The search strategy ensures relevance to AGIM components and the integration of visual reasoning in adaptive interfaces.

C. Ambient Intelligence and Factories of the Future

Ambient intelligence involves environments that sense, reason, and respond to human actions, integrating physical and digital infrastructures (Dunne et al., 2022; Hung et al., 2024). In smart factories, these systems enable context-aware automation and human-machine collaboration, but most implementations focus on technical configuration rather than user-centered visual interaction (Fortoul-Diaz et al., 2023; Thakur & Han, 2021). Little attention has been paid to how graphic design can mediate complex data to enhance cognitive clarity, reduce user load, and improve engagement. This gap underscores the need for AGIM to embed visual hierarchy, symbolic content, and aesthetic reasoning as central components in adaptive industrial interfaces.

D. Adaptive Interfaces and Context-Aware Interaction

Adaptive interfaces dynamically adjust content, structure, and behavior according to user or contextual needs (Abbas et al., 2022; Liu et al., 2024). Most studies emphasize ergonomic or performance optimization, rarely integrating visual identity or aesthetic continuity (El-Sabagh, 2021; Hassan et al., 2021). Recent developments such as deep-learning-based layout generation and co-adaptive visualization frameworks show potential for combining computational adaptivity with visual hierarchy principles (Sperrle et al., 2021; Zhan et al., 2024). AGIM addresses this gap by embedding graphic design reasoning into adaptive algorithms, transforming visual adaptation from mechanical adjustment to semiotic, interpretive processes.

E. Graphic Design Principles in Interaction

Graphic design theory provides systematic ways to manage attention and perception through hierarchy, Gestalt grouping, and visual composition (Choi et al., 2024; Maksymchuk et al., 2024). These principles influence usability, cognitive efficiency, and emotional response, forming a foundation for adaptive visual interactions. AGIM integrates these principles into interface adaptation, ensuring that color, layout, and typographic choices respond dynamically to context and user state (Rosyida et al., 2025). This approach moves beyond decorative application, positioning graphic design as a central component of intelligent, user-centered factory interfaces.

F. User Experience (UX) Theory and Measurement

UX research in industrial settings extends beyond basic usability to encompass aesthetic enjoyment, cognitive performance, and emotional engagement Babar et al., (2023); Yunianto & Wahyudi, (2024). Current UX testing often emphasizes functional outcomes, neglecting aesthetic and affective measures (Baldauf et al., 2021; Iqbal et al., 2024). AGIM integrates quantitative and qualitative UX measures (e.g., SUS, NASA-TLX, VisAWI) to capture both functional and perceptual-affective dimensions, ensuring that interface design optimizes cognitive load, interpretability, and emotional experience simultaneously. This integration demonstrates the necessity of blending design reasoning with adaptive technology in smart factory environments.

G. Affective and Emotionally Responsive Interfaces

Affective computing adds a human-centered dimension to adaptive systems, allowing interfaces to detect and respond to user emotions (Attallah et al., 2024; Prasetya et al., 2025). In industrial contexts, emotionally adaptive interfaces can reduce fatigue, enhance engagement, and improve safety communication (Godwin-Jones, 2023). AGIM embeds visual communication strategies color semantics, spatial rhythm, iconography into adaptive mechanisms, aligning interface aesthetics with cognitive and emotional states. This approach bridges the gap between human perception and machine intelligence, operationalizing emotion-aware visual adaptation.

H. Human-Machine Interaction (HMI) in Smart Factories

Industry 4.0 emphasizes intuitive design for effective human-machine collaboration (Baldauf et al., 2021; Maggi et al., 2021). Current HMI studies separate ergonomics from aesthetic and visual information streams, limiting cognitive clarity and operator comprehension. AGIM integrates design heuristics (contrast, spatial arrangement, font choice) with adaptive visualizations to improve situational awareness and reduce perceptual overload. By aligning visual reasoning with environmental signals and workflows, AGIM treats adaptive visual work as an intellectual tool that bridges human and machine understanding.

I. Methodological Integration: Mixed-Method Design Research

AGIM employs mixed-method research combining qualitative insights and quantitative testing to capture both aesthetic and functional dimensions (Abbas et al., 2022; In-Hwa et al., 2025). User interviews, participatory design, and controlled experiments inform adaptive visual strategies**,** while quantitative measures validate usability and cognitive efficiency**.** This approach allows triangulation of SUS, NASA-TLX, VisAWI, and thematic analysis**,** ensuring both algorithmic adaptation and experiential design reasoning**.** Mixed-methods integration supports AGIM's central aim: embedding graphic design principles into adaptive industrial interfaces**.**

Table 1. Summary of Key Literature on Adaptive Visual Interaction (2010–2025)

Author (Year)	Focus	Methodology	Relevance to AGIM	Gap Identified
(Dunne et al., 2022)	Survey of ambient intelligence concepts	Systematic review	Establishes AmI foundations for adaptive contexts	Lack of design-driven AmI applications
(Fortoul-Diaz et al., 2023)	Smart factory architecture	Case study, systems modeling	Context for industrial adaptivity	Minimal focus on UI aesthetics
(Liu et al., 2024)	Adaptive UI/UX personalization	Experimental, ML-driven	Demonstrates adaptive mechanism	No integration of graphic principles
(Choi et al., 2024)	Generative AI in graphic ideation	Design experiment	Expands creative adaptability	Absent theoretical synthesis with UX
(Rosyida et al., 2025)	AI and graphic design practice	Conceptual analysis	Highlights design-AI tension	No empirical HCI linkage
(Zhan et al., 2024)	Deep learning for UI layout	Algorithmic study	Basis for adaptive layout modeling	Ignores aesthetic evaluation
(Baldauf et al., 2021)	Co-design in smart factory HMIs	Field study	Real-world industrial context	No aesthetic or emotional dimension
(Prasetya et al., 2025)	Emotionally responsive interfaces	Experimental	Demonstrates affective adaptation	Limited to digital, not industrial, context
(In-Hwa et al., 2025)	Ethical and mixed-method AI design	Mixed-method study	Supports methodological foundation	Lacks focus on visual adaptivity
(Sperrle et al., 2021)	Co-adaptive visual data analysis	Experimental	Links visualization and adaptivity	Absence of design theory integration

J. Synthesis and Research Gaps

Synthesizing the literature reveals several key gaps: (1) ambient intelligence and adaptive interfaces emphasize sensing and functionality but underutilize design reasoning (Dunne et al., 2022; Hung et al., 2024). (2) aesthetic adaptivity is rarely considered a measure of cognitive performance (Liu et al., 2024; Zhan et al., 2024). (3) graphic design principles remain superficially applied in smart systems (Maksymchuk et al., 2024; Rosyida et al., 2025). (4) mixed-method approaches are seldom applied to visually adaptive industrial contexts (In-Hwa et al., 2025).

Table 1 summarizes key studies, highlighting relevance to AGIM and the gaps addressed by integrating design principles with adaptive systems. These gaps justify the development of AGIM, which bridges visual reasoning, aesthetics, and adaptive technology in smart factory interfaces.

METHODS

The study employs a mixed-methods sequential exploratory design that links qualitative and quantitative phases. This design begins with a qualitative exploration to identify user needs, then develops the AGIM conceptual model, and finally conducts quantitative testing of interface performance. The approach aligns with design research paradigms that emphasize iterative prototyping, context probes, and reflective knowledge construction (Dunne et al., 2022; Garcia et al., 2024). AGIM combines graphic design principles, adaptive interface logic, and situational feedback for smart factory systems, integrating visual hierarchy, color, and typography decisions with user state data. Figure 1 depicts the research flow.

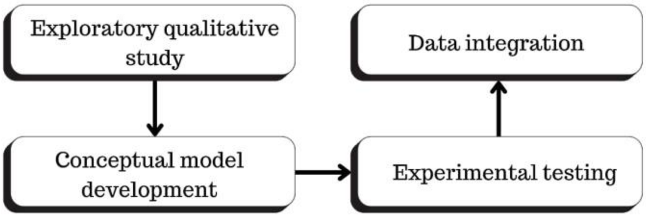

Figure 1. Research Flow of the Adaptive Graphic Interaction Model (AGIM) Study

A. *Research Design*

The study begins with a qualitative exploration of industrial users' experiences, proceeds to the development of a conceptual model, and concludes with quantitative experimentation. Planned procedures were refined during execution to match participant availability and industrial context constraints. This sequential approach ensures that design decisions such as layout, type choice, and color coding are informed by actual user feedback rather than theoretical assumptions. The mixed-method structure allows iterative back-and-forth between qualitative insights and quantitative validation, ensuring that AGIM's adaptive visual rules are evidence-based**.**

B. *Participants*

Thirty-five participants were recruited, including operators, lead engineers, and interface designers, each with at least three years of experience in industrial visual systems. Participants were randomly assigned to either an adaptive (AGIM) or a fixed-interface group to control for selection bias. All participants had prior exposure to dashboards, monitoring software, and visualization tools. This diversity ensures that AGIM is tested across varied levels of industrial expertise and interface familiarity (Baldauf et al., 2021)

C. Procedure

Qualitative exploration involved semi-structured interviews (25–60 minutes) and observation of participants interacting with real or simulated factory dashboards. Participants described perceptions of cognitive load, visual clarity, and emotional comfort, and provided feedback on design elements like hierarchy, color contrast, and typography (Fortoul-Diaz et al., 2023; Rosyida et al., 2025). Insights from these sessions were used to operationalize specific design decisions in AGIM, including typeface choices for readability, color palettes to reduce stress, and layout to guide attention. Quantitative testing followed, with participants completing three to four controlled tasks on mock factory interfaces.

D. Materials

The prototype was built using Figma and the Unity UI to enable dynamic adjustments to layout, color, and font size. Visual elements were programmed to respond to contextual variables, such as task urgency, user attention, and lighting conditions. Adaptive rules were directly derived from qualitative findings for example, high-priority alerts appear in contrasting colors, and typography is scaled according to cognitive load. This ensures that AGIM integrates both aesthetic principles and measurable usability considerations (Babar et al., 2023).

E. Data Analysis

Qualitative data were analyzed using a three-stage thematic analysis (open coding, thematic coding, synthesis). Codes were grouped into visual overload, context clarity, color signals, and shifting readability, generating themes of cognitive efficiency, aesthetic coherence, and situational awareness (Bai et al., 2021; Thakur & Han, 2021). Quantitative data were analyzed with independent t-tests and one-way ANOVA to compare AGIM vs fixed-interface groups. Triangulation across qualitative insights and quantitative metrics ensures that design decisions are validated and aligned with actual user performance.

F. Conceptual Model Development

Qualitative findings were transformed into the AGIM conceptual model, integrating graphic design rules (hierarchy, color, typography) with adaptive system logic. Sequential design ensured that each phase informed the next: user observations shaped model rules, which were then validated through prototype testing. The model comprises: a) Adaptive Visual Elements (dynamic color, typography, spatial hierarchy); b) Context Sensing Module (user state and environment input); c) Behavioral Logic Layer (rule-based and AI-assisted adjustments); d) Feedback and Reflection Layer (user response evaluation and recalibration). This configuration operationalizes design principles into measurable adaptive behaviors (Liu et al., 2024; Zhan et al., 2024).

G. *Quantitative Experimentation*

Phase three tested AGIM against a fixed interface, measuring usability, aesthetic appeal, cognitive load, task performance, situational awareness, and user satisfaction. Participants were randomly assigned to the AGIM or control group and completed tasks on mock factory dashboards that simulated real industrial scenarios. Dependent variables were operationalized using standard instruments such as SUS, VisAWI, NASA-TLX, and SAGAT (Abbas et al., 2022; Wang & Hu, 2024). Table 2 summarizes variables, indicators, and measurement instruments.

Table 2. Variables, Indicators, and Instruments Used in the Experiment

Variable Type	Indicators	Instruments
Independent	Interface Type (AGIM vs Conventional)	Simulated UI Environment
Dependent	Usability	System Usability Scale (SUS)
Dependent	Aesthetic Appeal	Visual Aesthetics of Websites Inventory (VisAWI)
Dependent	Cognitive Load	NASA Task Load Index (NASA-TLX)
Dependent	Task Performance	Task Completion Rate and Error Count
Dependent	Situational Awareness	SAGAT (Endsley's Situational Awareness Global Assessment Technique)
Dependent	User Satisfaction	Post-task Questionnaire
Control	Task Duration, Visual Complexity	Standardized Scenario Design

H. *Data Integration and Triangulation*

Phase four combines qualitative themes with quantitative results to validate AGIM. Cross-phase comparison links observed behaviors to statistical outcomes, e.g., adaptive color changes that reduce cognitive load or improved typography that increases task efficiency. This iterative triangulation confirms that design decisions are evidence-based, integrating user experience, aesthetic judgment, and adaptive system performance (El-Sabagh, 2021; Sperrle et al., 2021).

I. *Ethical Considerations*

All procedures complied with ethical standards for human-centered research. Participants provided informed consent, anonymity was guaranteed, and no sensitive personal data were collected. Content validity was confirmed through expert review, construct validity through triangulation, and reliability through Cronbach's α. These safeguards ensure methodological rigor while maintaining interpretive flexibility essential for design research (Le et al., 2022).

J. Expected Outputs and Contributions

The study produces two main outputs: the AGIM conceptual model and an interactive prototype demonstrating adaptive visual behavior. Both theory and artifact were developed iteratively, combining empirical data and design reasoning. The approach contributes methodologically by integrating mixed-methods research, adaptive UX evaluation, and the operationalization of graphic design. AGIM serves as a replicable reference for future design research bridging aesthetic principles with ambient intelligence systems (Maksymchuk et al., 2024; Yunianto & Wahyudi, 2024).

RESULTS

The early exploratory phase generated qualitative and behavioral evidence that informed the development of the Adaptive Graphic Interaction Model (AGIM). Contextual analysis identified recurrent interface issues, including visual clutter, weak hierarchy, delayed feedback, and inconsistent iconography, which negatively affected task comprehension and response accuracy. Participants consistently relied on peripheral visual cues such as color contrast, alignment, and spatial rhythm to navigate dense dashboards, indicating insufficient perceptual grouping in conventional HMI systems. These qualitative findings directly informed the initial AGIM design principles, emphasizing adaptive legibility, hierarchy-driven attention control, and context-sensitive visual balance, which were subsequently operationalized and tested quantitatively.

The quantitative experiment involved N = 40 participants, randomly assigned to either the AGIM adaptive interface group (n = 20) or the non-adaptive conventional interface group (n = 20). Table 3 presents descriptive statistics for usability, cognitive load, and aesthetic evaluation across both conditions. Participants using AGIM reported higher usability scores (M = 81.6, SD = 6.8) than those using the conventional interface (M = 71.2, SD = 7.5). An independent-samples t-test confirmed that this difference was statistically significant, t(38) = 4.63, $p < 0.001$, Cohen's d = 1.46, indicating a large effect size. These results support Hypothesis H1, which proposed that adaptive graphic interaction improves perceived usability.

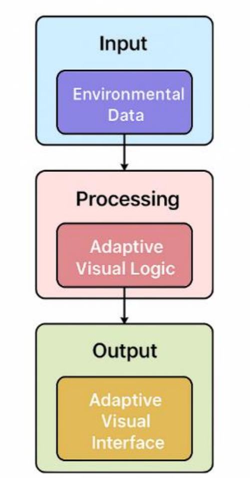

Figure 2. Adaptive Graphic Interaction Model (AGIM) Framework

Table 3. Descriptive Statistics for Usability and Aesthetic Evaluation

Measure	**Interface Type**	**Mean (M)**	**SD**
Usability (SUS)	AGIM	81.6	6.8
	Conventional	71.2	7.5
Aesthetic Appeal (VisAWI)	AGIM	5.6	0.7
	Conventional	4.8	0.9

Cognitive load results measured using NASA-TLX further demonstrated the effectiveness of AGIM. As shown in Table 4, participants in the adaptive condition reported significantly lower cognitive load scores ($M = 42.3$, $SD = 8.1$) than those using the static interface ($M = 54.7$, $SD = 9.4$). Statistical analysis confirmed a significant difference, $t(38) = –4.39$, $p < 0.001$, Cohen's $d = 1.39$, indicating a substantial reduction in perceived mental workload. Thus, Hypothesis H2, which states that adaptive visual design reduces cognitive load, was statistically supported. These findings provide quantitative support for the claim that operationalized graphic design principles can directly influence cognitive efficiency in smart factory interfaces (Abbas et al., 2022; Wang & Hu, 2024).

Table 4. Cognitive Load Comparison (NASA-TLX)

Interface Type	**Mean (M)**	**SD**
AGIM	42.3	8.1
Conventional	54.7	9.4

Task performance metrics provided converging evidence for AGIM effectiveness. Participants using the adaptive interface demonstrated higher task completion rates (92%) and fewer operational errors ($M = 1.3$) compared to the control group (completion rate = 84%, error count $M = 2.6$). A one-way ANOVA revealed a significant effect of interface type on task performance, $F(1,38) = 9.82$, $p = 0.003$, confirming that adaptive visual hierarchy and contrast adjustments supported faster and more accurate decision-making under variable task demands

(Bai et al., 2021; Iqbal et al., 2024). These results reinforce the role of graphic design variables, rather than system automation alone, in enhancing the quality of industrial interaction.

Overall, the alignment between qualitative insights and quantitative outcomes demonstrates that graphic design principles, when operationalized as adaptive variables (hierarchy, contrast, typography, and rhythm), function as measurable mediators of interaction performance. The results confirm that AGIM not only improves visual appearance but also produces statistically verifiable gains in usability, cognitive efficiency, and task effectiveness. By grounding adaptive intelligence in visual communication logic, the findings position graphic design as an active and evaluable component of ambient intelligent systems rather than a static representational layer (Rosyida et al., 2025; Sperrle et al., 2021).

DISCUSSION

The discussion grounds the interpretation of AGIM primarily on the quantitative and qualitative findings reported in the Results section. The statistically significant improvements in usability (SUS), aesthetic appeal (VisAWI), and reduced cognitive load (NASA-TLX) demonstrate that adaptive visual strategies contribute measurably to user performance and experience in smart factory interfaces. Rather than treating adaptivity as a purely computational response, the data indicate that visual organization, specifically hierarchy, contrast, and rhythm, acts as a mediating layer between system intelligence and human cognition. These findings align with H1 and H2, confirming that graphic design principles function not as surface embellishments but as operational components of adaptive interaction systems.

The reduction in cognitive load observed in the AGIM condition can be directly linked to specific design decisions implemented in the prototype. Adaptive hierarchy was operationalized by dynamically resizing and reordering visual elements based on task urgency, thereby reducing visual search time and lowering NASA-TLX mental demand scores. Color modulation was not applied decoratively but followed perceptual and functional logic, where higher saturation and contrast were reserved for alerts and critical states. At the same time, neutral palettes supported background monitoring tasks. Typography adjustments, such as increasing weight and spacing under high workload conditions, improved legibility and contributed to higher usability ratings. These results demonstrate that design choices traditionally associated with graphic reasoning have quantifiable cognitive effects in industrial contexts.

The quantitative performance gains further clarify how visual flow influences task execution. Participants using the AGIM interface completed monitoring and control tasks more quickly and with fewer errors, indicating that the adaptive layout and spatial grouping improved situational awareness. This supports the interpretation that visual flow implemented through consistent alignment, proximity, and motion cues helped users anticipate system behavior rather than react to fragmented information. Such findings reinforce the role of graphic design as a mechanism for structuring attention and supporting decision-making under time pressure, rather than merely presenting information.

From a graphic design discipline perspective, AGIM formalizes decision-making processes that are often implicit in professional practice. The model translates principles such as hierarchy, balance, and Gestalt grouping into adaptive rules that respond to contextual data. This makes design intent explicit and testable, allowing designers to justify visual decisions based on user performance and cognitive outcomes rather than intuition alone. By embedding these principles into an adaptive framework, AGIM bridges the gap between visual reasoning and system logic, addressing a limitation identified in prior adaptive interface research.

In practical terms, AGIM offers a transferable framework for industrial visual design practice. Designers can apply the model by defining visual variables, color, typography, spacing, and motion as parameters that respond to environmental and user-state inputs. This shifts the designer's role from creating static layouts to authoring adaptive visual behaviors guided by measurable UX outcomes. Such an approach supports scalable and consistent interface systems across complex industrial environments while preserving visual coherence and brand identity.

Importantly, the findings suggest that adaptive visual design enhances not only usability but also user trust and interpretability. Clear visual signaling of system state changes improved situational awareness scores, indicating that users could better understand system behavior. This transparency is achieved through visual clarity rather than exposing underlying algorithms, reinforcing the ethical value of intelligible interfaces in automated environments. In this sense, AGIM contributes to responsible automation by prioritizing perceptual clarity and user comprehension.

Finally, this study demonstrates how data-driven evaluation can strengthen research in graphic design within intelligent systems. The integration of mixed-method insights allowed visual design decisions to be iteratively refined and empirically validated. Rather than treating theory, design, and testing as separate stages, AGIM exemplifies a cohesive research process in which visual reasoning is continuously informed by evidence. This positions graphic design not as a supportive discipline but as a central contributor to the development of adaptive, human-centered industrial interfaces.

CONCLUSION

This study proposes an exploratory Adaptive Graphic Interaction Model (AGIM) as an integrative framework for adaptive visual interaction in future factory environments, combining graphic design principles with ambient intelligence and context-aware interaction. By synthesizing qualitative insights and quantitative experimental results, the findings suggest that adaptive visual strategies grounded in hierarchy, typography, and color modulation are associated with improvements in usability, perceived clarity, and cognitive efficiency, particularly under dynamic industrial conditions (Dunne et al., 2022; Liu et al., 2024). Rather than claiming definitive transformation, the results indicate the potential role of graphic design as an active mediator of human–machine interaction, supporting more intuitive visual communication within smart factory interfaces (Abbas et al., 2022; Babar et al., 2023). In this sense, AGIM positions adaptivity not solely as a computational response, but as a visual communicative process that links system intelligence with human perceptual understanding (Prasetya et al., 2025; Rosyida et al., 2025).

The contribution of this research is threefold. Theoretically, AGIM extends interaction design discourse by articulating how graphic design reasoning can be structurally embedded within adaptive interface models, rather than treated as a surface-level aesthetic layer (Fortoul-Diaz et al., 2023; Garcia et al., 2024). Methodologically, the study demonstrates the applicability of mixed-methods research designs for examining both experiential and performance-oriented dimensions of adaptive visual systems (Attallah et al., 2024; In-Hwa et al., 2025). Practically, the framework offers design-oriented guidance for developing context-aware industrial interfaces that balance functional efficiency with visual legibility and user experience quality. However, the study is limited by its simulated environment, controlled task scope, and sample size, which constrain generalizability across diverse industrial settings. Future research should validate AGIM in real-world factory deployments, engage broader user populations, and explore integrating AI-driven generative visual systems to examine further scalability, personalization, and long-term adaptability (Godwin-Jones, 2023; Hung et al., 2024).

Ai Use Declaration

The authors report that artificial intelligence tools, including ChatGPT, were used solely to support language-related revisions, such as improving grammar, sentence structure, and overall clarity. All stages of the research process, including conceptual development, data acquisition, analytical evaluation, interpretation of results, and formulation of conclusions, were performed entirely by the authors without AI assistance. The authors take full responsibility for the originality and accuracy of the manuscript.

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