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Stimulating design ideation with artificial intelligence: present and (short-term) future

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Abstract

The role of Artificial Intelligence (AI) in design is clearly growing. One of the tenets of the paper is that stimulation could be among the design processes mostly benefitting from the introduction of AI. Available contributions have been reviewed to understand the current support AI can give in design inspiration and ideation. We also reflected on what AI should and ahould not do in the future: a framework is proposed. Based on the reviewed contributions, in no case, AI is seen as a substitute of designers. Most contributions originate from the IT domain and have a demonstrative purpose.

Keywords: design process, artificial intelligence (AI), human behaviour, inspiration, review

1. Introduction

According to Verganti et al., (2020), Artificial Intelligence (AI) has the potential to both boost the use and effectiveness of established design methods, but also overturn established design practices. The profoundness of this impact will likely depend on the way designers will manage AI and if they will be able to use AI as a partner and not as a substitute of their skills and creativity.

The starting point of this paper is based on the recent work of Thoring et al. (2023), who explored the potential of AI as a companion to augment designers' capabilities. AI is able to quickly generate numerous variations of a design. However, these scholars argued that AI, in its current state, is not able to perform the following tasks: distinguishing good and bad designs, making adequate choices, teaching the rationale of decisions and concepts to others, and transferring concepts to other contexts. This does not exclude that AI might (in the future) be able to support the human designer in these tasks, which will lead to the concept of an "augmented designer", i.e., a close human-AI collaboration. Still with reference to Thoring et al. (2023), the relevance was emphasised of AI's creative capabilities in the design field and the range of design artefacts that can be artificially generated, i.e., texts, images, sounds, videos, and 3D models. These artefacts resonate well with the representations used in design (Gonçalves et al., 2014; Dorta et al., 2016) and with the forms of objects used as stimuli for ideation or sources of inspiration (Borgianni et al., 2020). Consequently, with this paper, we aim to have a closer look at stimuli in the context of AI-supported inspiration and ideation in early design stages. With this lens, we took inspiration from (Tang et al., 2019) and identified four areas where AI can facilitate the human designer: (1) ideation, (2) generation of stimuli (3) stimulation, and (4) search for stimuli. More details are to be found in Section 3. More specifically, the goal of this paper is to understand through a representative sample of papers gathered through a literature review to which extent can AI, in its current development stage, influence the processes of design stimulation and ideation, and infer AI's further

potential. In fact, inspiration already ranges among established AI-powered design activities in Yüksel et al.'s (2023) recent review on AI contribution to engineering design. However, the understanding of the variety of possible effects of AI on designers' creativity is still scattered. We go beyond existing reviews, as we specifically address the role of AI for design inspiration and ideation as design activities, rather than addressing specific domains (e.g., Pena et al., 2021).

2. Relevant background on design inspiration and stimuli

As widely accepted in the literature, ideation is critical to successful design outcomes, but the early stages of the design process are poorly supported by methods and tools, because of design's inherent high levels of ambiguity and uncertainty (O'Halloran et al., 2019). As an alternative to the adoption of standardized methods, evidence suggests that designers engage in both spontaneous and deliberate search for sources of inspiration while designing (Gonçalves et al., 2016). Any priming action, prompt, driver, trigger or source of inspiration will be generally referred to as "stimulus" hereinafter. Stimuli usually support designers in exploring the problem and solution spaces, mapping relations, functions and paradigms. In this context, design experiments leveraging stimuli have targeted the enhancement of ideation and problem-solving processes by fostering creativity and reducing fixation phenomena (Crilly & Cardoso, 2017). Sun and Münster (2018) revealed the large number of parameters that are leveraged and controlled in ideation and stimulation activities and elucidated the complexity of the involved phenomena. Among others, the kind of cognitive stimulation, and especially the distance between the stimulus source and what is currently designed and ideated, play a relevant role in this sense (Gonçalves et al., 2013), but the predictability of inspiration and fixation phenomena is still hard to capture. Moreover, people benefit from stimulation mechanisms to different extents and prefer certain forms of stimulation (pictures, videos, text, etc.) over others (Borgianni et al., 2020; Blandino et al., 2023). The possibility to vary and adapt forms of stimulation is supposed to overcome the pros and cons of the different modalities of stimulation regarding creativity and fixation (Borgianni et al., 2020).

While the availability of a considerable quantity of stimuli in different forms seems beneficial, designers typically lack the means to select and navigate them appropriately, resulting in ineffective exploration (Gonçalves et al., 2016). Then, to make the process more effective, the stimulation activity should be ideally customized and articulated according to designers' preferences, idiosyncratic and immediate needs that reflect different phases of the design process (e.g., incubation, specification of ideas, exploration, elaboration). This suggests that ideation can substantially benefit from considering cognitive aspects in design (Gonçalves et al., 2016) to monitor immediate designers' cognitive aspects, feelings, emotions, and behaviour. In design, the most studied cognitive phenomena are efforts, stress and frustration designers may exhibit (Borgianni and Maccioni, 2020). In addition, cognition also plays a role during ideation (Gonçalves & Cash, 2021), for instance in activation of prior knowledge and/or mental set in the promotion of insight and problem-solving. Creative ideation could be fostered by a variety of methods: although some scholars have evidenced that a state of flow (immersion in own thoughts) is tightly connected to ideation (Csikszentmihalyi, 1997), others suggested that creativity could improve via feedback and ongoing stimulation (Fink et al., 2010). However, the effectiveness of steering the stimulation process through cognitive data is both still to be fully demonstrated and difficult to test, as it would require the use of biometric systems the designer should be equipped with.

As tailored solutions for directed stimulated ideation are needed and cannot be developed by readapting traditional methods, an opportunity can be represented by AI. In this context, we believe that AI can disclose hidden links between required stimulation means and designers' actions. AI can propose an abundance and a higher-level variation of stimuli also because of AI's ability to generate new things, prompted by the designer. Because of the manifold ways AI can potentially interact with the process involving the search for stimuli, cognition, inspiration and ideation, it is relevant to consider which areas are currently being addressed and which questions deserve more attention in the future. Therefore, we believe that an overview of the literature on AI in these design activities is valuable to fully understand how AI can facilitate this intricate process.

3. Overview of literature contributions on stimulation and ideation supported by Artificial Intelligence

According to Tang et al. (2019), AI-based ideation is a process involving the generation of innovative and practical design concepts. It is categorised into stimuli-based and interaction-based methods. Stimuli-based approaches offer external inspiration to designers, while interaction-based methods facilitate group collaboration and feedback. AI techniques can enhance both ideation types by retrieving or generating stimuli, using natural language processing or image generation models, and creating intelligent virtual moderators or chatbots for online brainstorming.

This background section is structured in line with the distinction of AI contributions proposed by Tang et al. (2019) and in consideration of our focus on stimuli. The most pertinent examples of AI applications in design stimulation for idea and concept generation are defined according to the different roles played by AI systems, in line with the areas shown in the Introduction section.

1. AI-supported ideation: AI proposes ideas, designs or solutions following stimuli provided by humans or other AI agents.
2. AI-supported generation of stimuli: AI generates stimuli autonomously or after the provision of some inputs; designers can avail of these stimuli as a result.
3. AI-supported stimulation: AI selects, elaborates or improves stimuli after the elaboration of various sources or datasets, which have not been initially constructed as stimuli databases.
4. AI-supported search for stimuli: AI is used as a human-activated support tool to search and identify appropriate stimuli out of a predefined set or collection of designs, or to organize and combine them.

We analysed the literature to identify the contributions pertinent to the areas above where a clear application of AI in design was found and described: this was the main criterion for inclusion of papers in this review. We used Google Scholar as a database, so that relevant terms (and combinations thereof) such as "AI", "Artificial Intelligence", "design", "inspiration" and "stimuli" could be searched in the full text of papers. The terms were combined, and the search was stopped when no relevant new contributions emerged from the search. More than 100 papers that appeared as pertinent contributions based on their title were analysed, but many were subsequently excluded, mainly because the presented AI applications did not directly support the design functions we focus on in this paper.

3.1. AI-supported ideation

In the first area, the following studies have explored AI's capabilities in proposing ideas and concepts. Chen et al. (2019) proposed an approach encompassing a semantic ideation network and a visual concepts combination model to enhance ideation through AI and data mining techniques. Stimuli are provided by the study participants who used either predefined models for inspiration or results of an Internet search. The latter gave rise to better results in terms of creativity.

The proposal presented in Zhu and Luo (2022) generates design ideas by using the United States Patent and Trademark Office as an input. Ideas are generated in text form, which can be subsequently evaluated by means of a technology semantic network based on patent data. As the outcomes of the AI system are just partially satisfactory, designers' own input on the ideas generated is essential.

The potential of text-to-image generators for design tasks is investigated by Paananen et al. (2023). The generators are tested in relation to supporting architectural design creativity during the early design stages. The generated images are in form of possible graphical design solutions. Based on the results, the research concludes that image generation can be a valuable part of the architectural design process, provided that design constraints and imaginative ideation are carefully considered.

Koch et al. (2020) introduced a digital mood board tool to support collaborative and intelligent ideation for designers. The system works following the collection of data including audio, video, interviews, and questionnaires. The generated digital mood boards convey design concepts, ideas, and emotions related to a design brief; hence, the outputs can be used as either design outcomes or stimuli for subsequent design phases or redesign actions.

The overview of studies focusing on AI-supported ideation through stimuli highlight that attempts are preliminary and in very different forms. Using AI tools to support ideation shows promise in how

designers are able to nudge and adjust the interaction with AI, potentially supporting designers' reflective practices. Although potentially stimulating, ideas generated by AI should be managed by designers.

3.2. AI-supported generation of stimuli

AI's potential to generate stimuli based on given prompts has been explored in the following studies. Maier et al. (2020) explained how AI can inspire creativity through various AI-based tools, such as image generators, design tools, and inspirational quote generators. This contribution highlighted the use of AI as a facilitation tool for co-located group brainstorming sessions, as demonstrated in the experimental study that compared human facilitators with a cognitive assistant employing natural language processing and AI.

Kim et al. (2021) introduced a co-creative design system known as the Collaborative Ideation Partner, which supports idea generation by providing stimuli varying in similarity to the user's design in two dimensions: conceptual and visual similarity. Additionally, the paper outlined an exploratory study evaluating the impact of AI inspiration on creativity. The results showed that distinct types of AI-generated stimuli have different effects on ideation outcomes and suggested further analysis of the cognitive processes involved in co-creation with Collaborative Ideation Partner.

In the work of Yun et al. (2022), an ideation support tool is presented using generative AI text for design inspiration aimed to support design creativity. The generated texts led to the gradual development of ideas with an increasing detail level.

Debowski et al. (2022) proposed a Virtual Collaborator prototype based on AI to stimulate creativity within idea generation. In particular, the system is capable of providing information, background knowledge, examples, images, sounds, and diverse perspectives to facilitate creativity during ideation. The prototype works through natural language processing, semantic analysis and keyword search to find relevant content from various sources.

Duan and Zhang (2022) introduced an AI-based method for generating diverse, coherent, and mentally evocative visual stimuli in the context of environment concept design. It addressed the challenges faced by designers in this field and proposed a novel approach that utilizes generative adversarial networks to produce images that can serve as inspiration during the design ideation process. The stimuli were subsequently assessed through interviews with design professionals in terms of the presumed effectiveness of the generated stimuli. The study found that the generated stimuli exhibited coherency, completeness, and a mental image-like quality.

Knops et al. (2023) introduced a human-centred AI collaboration tool that enhances collaboration speed, creativity, and effectiveness in co-ideation and co-creation sessions. It addressed key challenges in human collaboration enhanced with AI, which include facilitating the design process, providing inspiration for exploration, and assisting in requirement understanding and definition. The role of AI is here to create stimuli for design inspiration, specifically through speech-to-text and text-to-image AI models.

Wang and Han (2023) investigated the influence on the creative ideation process of two distinct types of stimuli, namely pictorial and generative. The latter were created through adversarial neural generative networks. The study involved a quantitative comparison of these two kinds of stimuli in the context of combinational design and explores how designers' experience affects the effectiveness of these stimuli. Based on the findings, generative stimuli contributed to a smoother creative process for designers compared to image stimuli. In addition, designers with more extensive design education tended to derive greater novelty and usefulness from generative stimuli.

In Lee and Chiu's (2023) study, AI is leveraged to create inspirational stimuli through a text-to-image generator. The study compared the influence of AI-generated visual stimuli against online visual stimuli (sourced from Pinterest) on product design, with a focus on the styling of a futuristic motorcycle. The scholars concluded that none of the two categories of stimuli was superior and rather highlighted their complementary nature.

Kim and Maher (2023) investigated the impact of an AI-based co-creative design tool that offers design inspirations based on conceptual similarity during the ideation process. The tool enabled users to collaborate with an AI partner during open-ended creative tasks, with the AI partner's role being to offer

inspirational images based on conceptual similarity. The AI-driven stimulations significantly influenced the novelty, variety, and quantity of ideas generated during human design ideation.
A peculiar case was presented by Zhou et al. (2020), where stimuli were provided in the fashion of design feedback. The scholars proposed an AI-augmentation method and conducted an experiment involving novice designers to evaluate the effects of AI feedback on their design outcomes, especially regarding creativity. The results indicated that AI augmentation enhances performance in fluency and style quality but not in flexibility and originality. The article emphasized that different forms of AI feedback may yield varying effects on design iterations.
Most of the reviewed papers on AI-aided generation of stimuli describe applications focused on the collaboration between AI and designers. The number of articles found and the way the outcomes of studies are assessed demonstrate a relative maturity of this kind of applications with a relatively positive impact on creativity.

3.3. AI-supported stimulation

A number of studies have focused on how AI can select, elaborate or improve stimuli to support designers. For instance, Singh et al. (2019) explored the potential of an AI-based mobile app to offer visual inspiration for design tasks, specifically by providing users with images that possess ambiguity, diversity, and the ability to evoke various interpretations, moods, and emotions. The app performance in image retrieval and its impact on design inspiration were assessed through a crowdsourcing experiment and a pilot study involving 8 participants. The main outcome of the study was the need to empower users to choose or update their image datasets.
In the work of Jin et al. (2021), an AI system was used to identify, extract and fine-tune visual stimuli from patents to be used by User Experience designers. This system enhanced designers' capabilities by providing guidance in generating innovative AI-powered ideas. The scholars proposed that AI can generate suitable stimuli in given circumstances based on humans' initial inputs; the so-created stimuli can be then evaluated by professionals.
Sarica et al.'s (2021) objective was to present a new AI-based methodology that leverages TechNet, a network of technical terms from patent texts, for idea generation in engineering design. The system provided stimuli and conceptual white spaces for ideation, which were then filled by designers with new ideas. The white spaces were featured by different analogical distances from the field of the design tasks, which prove to play a considerable role in terms of creativity metrics.
Wan and Lu (2023) introduced a web-based digital mood board that integrates AI-generated images into the character design ideation process. The scholars' approach allowed designers to articulate their needs and communicate explicitly with the AI, emphasizing the collaboration between human creativity and AI assistance. The system is evaluated as enjoyable, explicit, and effective for exploring AI-generated images.
The overview of papers on AI-supported stimulation is relatively small. Yet, it can be seen as complementary to the works described in Section 3.2, which highlight the collaborative interaction designers can have with an AI support. Based on this review, integrations among different contributions are difficult to foresee because of the variety of the design representations and sources leveraged.

3.4. AI-supported search for stimuli

The last category of reviewed studies focusses on the potential of using AI to support the search and selection of relevant stimuli. Liao et al. (2020) employed AI as an inspirational tool for designers during the early stages of design, focusing on creativity and decision-making. The developed framework was derived from think-aloud protocols extracted from 30 designers. Specific AI tools that turned useful in this contribution include image translation, image synthesis, image editing, image creation, and style transfer. AI's potential role in design ideation was categorized into representation creation, empathy trigger, and engagement, which are key components of the proposed AI-augmented design support framework.
In the work of Zhao et al. (2021), AI was utilized to extract features from designers' sketches through a deep learning network. These features were used to retrieve visually similar images from a vast logo database, providing image stimuli to enhance designers' ideas. As an original aspect of this contribution,

AI analysed designers' visual behaviour when interacting with the image stimuli and selects images with longer fixation times as the most valuable for stimulating creativity. Based on the results of experiments, this stimulation process was mostly useful in divergent design phases.
In the study of Wahl et al. (2022), the primary objective was to examine the influence of diverse sets of pre-structured idea stimuli, organized by an AI-supported clustering, on ideation outcomes. This variation in idea stimuli revolved around quantity and semantic diversity. The findings indicated that idea novelty benefited from exposure to a broad range of ideas originating from various clusters. This effect was further amplified when participants possessed domain-specific knowledge. However, this broader search was detrimental to idea feasibility and specificity. The study's implications suggest that designers seeking innovative ideas can benefit from AI-supported clustering tools but should be cautious of some elements of vagueness inherent to their functioning.
Kwon et al. (2023) investigated the process of designers searching for inspirational stimuli through an AI-enabled multi-modal search platform. The study specifically explored how different input modalities, as well as the level of design expertise, affect search behaviours and outcomes. The scholars presented the results of a design exploration task where both student and professional designers used the platform to find 3D-model parts for inspiring their solutions to a designated design challenge. Keyword searches were more frequent and more often led to expected results. Workspace searches were more likely to yield unexpected results, especially in new searches. Students differed from professionals in their search behaviours, evaluation of results, and acceptance of their designs.
The contributions we gathered in this subsection are still quite explorative and do not appear to show mature systems to support designers in the search for stimuli. Most studies focus on the behaviour of designers who are given the chance to use AI while they willingly approach the inspiration process. As such, it seems an area that deserves more attention.

4. Reflection and discussion

4.1. Main evidence from the literature

Based on the findings from the literature, AI support in stimulation and ideation processes was successfully distilled in four areas in line with (Tang et al., 2019), see the numbered list in Section 3.
For area 1 (AI-supported ideation), the literature reported various cases where AI produced ideas based on provided constraints, but the outcomes were just partially satisfactory. In most cases, the designers' own input on the ideas generated was still required, and the given design constraints had to be carefully considered. We found that researchers have mostly addressed questions and applications related to the second area: AI-generated stimuli are the most common typology of AI support to ideation and various techniques are proposed. The technology for this purpose appears to be mature for this task. The third area (AI-supported and -generated stimuli) is not as elaborated in the found literature. In a few cases, AI is used to provide suggestions to designers in terms of actions aimed to progress in the design process. Rather, many AI systems browse and offer stimuli to designers but distinguishing good and bad stimuli according to design objectives is not yet possible. The fourth area (AI-supported search for stimulation) includes multiple cases, but the corresponding task is overall poorly covered. Many systems have predefined forms of stimuli offered to designers, which are usually visual representations. Also, when multiple forms of stimuli representations are provided, this is not affected by circumstances concerning the designer. In one case only (Zhao et al., 2021), the choice of stimuli takes place after analysing the designer's eye movement. In conclusion, it can be stated that no AI system analysed in the literature has verified the capability to evaluate data with sufficient effectiveness in selecting the most appropriate stimuli. AI can straightforwardly propose options, but human intervention remains essential. Overall, we can state that the presumed AI capabilities of disclosing links between stimulation means and designers' actions (see Section 2) have not been exploited and turned into desired design applications. This is the starting point of our future work.
Moreover, no contribution sees AI as a substitute for human activities. Instead, it is viewed as a support or 'enhancement' for designers, especially in the area of inspiration for concept creation, which is in line with Thoring et al. (2023). Consequently, we argue that, despite ongoing research, the adaptation of AI technologies for the scopes of stimulation in early design is still at an experimental stage of development.

4.2. Moving forward and considering ethical issues: threats and opportunities

As a result of the findings from our review, it seemingly emerges that AI can support the designer with several tasks, but some still need to be performed by the human designers themselves. The agenda for future research by Thoring et al. (2023) presented several ideas on what needs to be achieved for AI to be even more of a support for designers. But, in ethical terms, how far should we go? Are there any tasks that maybe AI could take over in the future – but should not? In parallel to the exploration of how AI can support ideation and design, a growing number of publications have focussed on ethical considerations of using AI in this context. For instance, questions about biases, accountability and transparency have emerged as crucial topics to leverage the rapid growth of AI tools (Loi et al., 2019; Kronqvist and Rousi, 2023). The potential biases are well known that can emerge from the available databases and algorithmic choices AI systems currently use (Shneiderman, 2020). Likewise, there is a risk of designers' over-reliance on AI tools, blindly trusting AI-generated responses, especially in the case of novice designers (Popescu and Schut, 2023). Consequently, and looking forward, it is essential to map what AI should or should not do in the context of design creativity. These considerations led us to develop the framework of AI support for stimulation in design ideation illustrated in Table 1. The framework is clearly the product of our thoughts after considering the risks associated with AI and the reading of the literature.

Table 1. Framework of AI-support for stimulation in design ideation

What AI can do	What AI cannot do - yet	What AI should do	What AI should not do
Generate stimuli based on given prompts or constraints	Select stimuli and distinguish good from bad ones	Support human designers by providing stimulation	Replace human designers by generating completely finished design solutions.
Create variations of specific stimuli	Transfer stimulation concepts to other contexts	Offer stimuli choices to the human designers	Nudge human designers in specific/limiting direction (risk of fixation)
	Externalise decisions for selecting specific stimuli	Accelerate design processes, by facilitating reflective practices	Make decisions without designers' appraisal
	Automatically provide stimuli support	Adapt to designers' cognition and emotions to provide suitable stimuli	

4.3. Additional reflections

We found surprisingly few considerations in the analysed literature in terms of what type of AI support would be appropriate for what situation. In a few cases, AI comes into play based on specific design phases. In other words, the way the AI system works does not depend on design situations or tasks. In one case only, scholars have reflected on the most effective situations in which the AI system can intervene and identified divergent phases as a preferred terrain (Zhao et al., 2021). However, also in this contribution, there are no different modalities of using the AI system; it has been just realized when better results are achieved.

A few more limitations become evident when looking at our literature analysis. First, many contributions originate from research in computer science. In these cases, the focus is on the usability of a standard or readapted AI tool in design ideation rather than its specific development for design purposes. Otherwise said, design is viewed here as a potential field of application of AI technologies. In any case, also when emphasis is not placed on design-related issues, many contributions evaluate outcomes through creativity metrics, which allows comparisons and aligns well with the literature published in design journals and conferences. Besides, creativity is considered as a reference target whatever the reference scientific domain of the analysed contributions. Second, when experiments are conducted, the number of participants is, on average, very low. In many cases, samples of participants include less than 10 people. This highlights the difficulty of generalizing the results and suggests that most proposed AI systems are to be considered prototypes, which is directly reported in some contributions. This aspect is

stressed by the fact that numerous contributions are published in conferences. On this basis and with regard to the level of achievement of the above tasks, we can infer that we are far from the creation of a standard effective AI system for ideation and stimulation in early design.

5. Conclusions and limitations

This review and critical analysis explore the role of AI in the creative design process, categorizing its assistance into four main areas: ideation, generation of stimuli, stimulation, and searching for stimuli. The boundaries of the AI applications considered in this study can be seen as a limitation of the paper. Actually, other AI systems might aid the process of design ideation in indirect ways, for instance through the identification, collection and management of customer needs (Li et al., 2021), which are commonly handled in the early design phases. In this respect, the reviewed AI applications might provide just a reduced framework of the activities AI can truly support to benefit design ideation and stimulation. Even if we consider the analysed sample of articles sufficiently representative, some relevant contributions might have not been identified in this non-comprehensive review because we closely looked at papers mentioning AI without using search terms representing AI sub-areas, such as Deep Learning, Neural Networks or Machine Learning. These terms will be properly considered in our future work, which includes a systematic and comprehensive literature review to encompass not only functions closely related to stimulation and ideation, but also ancillary functions, such as the identification of consumer requirements and the organization of design teams. Once a comprehensive sample will be collected, it will be useful to classify the contributions through categories and subcategories, including design functions and AI-used algorithms. This could lead to identify the existence of potential connections between design activities and most appropriate AI tools supporting them.

Based on the data collected and contributions analysed so far, AI demonstrates promising capabilities in generating stimuli and supporting ideation, but it struggles in evaluating data to select the most appropriate stimuli. Despite advancements in technology, we are far from achieving a seamless collaborative interaction between designers and AI systems in the creative design process. Ethical concerns are significant, raising questions about the suitable degree of AI integration in the creative process. The reviewed literature positions AI as a support for designers, according to the perspective that AI should enhance human capabilities rather than replace them. As the field progresses, ethical considerations regarding the definition of AI's role in design become increasingly crucial.

However, the literature falls short in addressing the appropriateness of AI support in various situations, emphasizing the experimental nature of current applications. Clear guidelines on when and how AI should intervene in the design process are lacking and are, thus, suggested in this paper based on our understanding and viewpoint. The analysis identifies limitations, with a focus on the usability of existing AI tools rather than the development of purpose-built tools for design. The prevalence of prototypes and a scarcity of participants in experiments highlight the distance from establishing a standardized, effective AI system for ideation and stimulation in the early stages of design.

In conclusion, the integration of AI into the stimulation-based creative design process is still in its experimental phases, demanding further research, ethical considerations, and the creation of specialized AI tools to realize its full potential. The ongoing journey toward a standardized and effective AI system for supporting ideation and stimulation tasks in early design presents both challenges and opportunities yet to be fully explored.

References

Blandino, G., Montagna, F., Cantamessa, M., & Colombo, S. (2023), "A comparative review on the role of stimuli in idea generation", *AI EDAM*, Vol. 37, e19. https://doi.org/10.1017/S0890060423000124

Borgianni, Y., & Maccioni, L. (2020), "Review of the use of neurophysiological and biometric measures in experimental design research", *AI EDAM*, Vol. 34, No. 2, pp. 248-285. https://doi.org/10.1017/S0890060420000062

Borgianni, Y., Maccioni, L., Fiorineschi, L., & Rotini, F. (2020), "Forms of stimuli and their effects on idea generation in terms of creativity metrics and non-obviousness" *International Journal of Design Creativity and Innovation*, Vol. 8 No. 3, pp. 147-164. https://doi.org/10.1080/21650349.2020.1766379

Chen, L., Wang, P., Dong, H., Shi, F., Han, J., Guo, Y., ... & Wu, C. (2019), "An artificial intelligence based data-driven approach for design ideation", *Journal of Visual Communication and Image Representation*, Vol. 61, pp. 10-22. https://doi.org/10.1016/j.jvcir.2019.02.009

Crilly, N., & Cardoso, C. (2017), "Where next for research on fixation, inspiration and creativity in design?", Design Studies, Vol., 50, pp. 1-38. https://doi.org/10.1016/j.destud.2017.02.001

Csikszentmihalyi, M. (1997), "Low and the psychology of discovery and invention", *Harper Perennial*, New York, Vol. 39.

Debowski, N., Tavanapour, N., & Bittner, E. A. (2022), "Prototyping a Conversational Agent for AI-Supported Ideation in Organizational Creativity Processes", In *HICSS*, pp. 1-10

Dorta, T., Kinayoglu, G., & Boudhraâ, S. (2016), "A new representational ecosystem for design teaching in the studio", *Design Studies*, Vol. 47, pp. 164-186. https://doi.org/10.1016/j.destud.2016.09.003

Duan, Y., & Zhang, J. (2022), "A Novel AI-Based Visual Stimuli Generation Approach for Environment Concept Design", *Computational Intelligence and Neuroscience*, Vol. 2022, pp. 8015492. https://doi.org/10.1155/2022/8015492

Fink, A., Grabner, R. H., Gebauer, D., Reishofer, G., Koschutnig, K., & Ebner, F. (2010), "Enhancing creativity by means of cognitive stimulation: Evidence from an fMRI study", *NeuroImage*, Vol. 52 No. 4, pp. 1687-1695. https://doi.org/10.1016/j.neuroimage.2010.05.072

Gonçalves, M., Cardoso, C., & Badke-Schaub, P. (2013), "Inspiration peak: Exploring the semantic distance between design problem and textual inspirational stimuli", *International Journal of Design Creativity and Innovation*, Vol. 1 No. 4, pp. 215-232. https://doi.org/10.1080/21650349.2013.799309

Gonçalves, M., Cardoso, C., & Badke-Schaub, P. (2014), "What inspires designers? Preferences on inspirational approaches during idea generation", *Design Studies*, Vol. 35 No. 1, pp. 29-53. https://doi.org/10.1155/2022/8015492

Gonçalves, M., Cardoso, C., & Badke-Schaub, P. (2016), "Inspiration choices that matter: the selection of external stimuli during ideation", *Design Science*, Vol. 2, pp. e10. https://doi.org/10.1017/dsj.2016.10

Gonçalves, M. & Cash, P. (2021), "The life cycle of creative ideas: towards a dual-process theory of ideation", *Design Studies*, Vol. 72, No. 100988. https://doi.org/10.1016/j.destud.2020.100988

Jin, X., Evans, M., Dong, H., & Yao, A. (2021), "Design heuristics for artificial intelligence: inspirational design stimuli for supporting UX designers in generating AI-powered ideas", *In Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems*, pp. 1-8. https://doi.org/10.1145/3411763.3451727

Kim, J., & Maher, M. L. (2023), "The effect of AI-based inspiration on human design ideation", *International Journal of Design Creativity and Innovation*, Vol. 11 No. 2, pp. 81-98. https://doi.org/10.1080/21650349.2023.2167124

Kim, J., Maher, M. L., & Siddiqui, S. (2021), "Collaborative Ideation Partner: Design Ideation in Human-AI Co-creativity", *In CHIRA*, pp. 123-130. https://doi.org/10.5220/0010640800003060

Knops, R., Şerban, B., & Houben, S. (2023), "Human-human collaboration enhanced with emerging technologies of AI", *In CHI'23: Workshop on Integrating AI in Human-Human Collaborative Ideation*.

Koch, J., Taffin, N., Beaudouin-Lafon, M., Laine, M., Lucero, A., & Mackay, W. E. (2020), "Imagesense: An intelligent collaborative ideation tool to support diverse human-computer partnerships", *Proceedings of the ACM on human-computer interaction*, Vol. 45, pp. 1-27. https://doi.org/10.1145/3392850

Kronqvist, A., & Rousi, R. (2023), "A quick review of ethics, design thinking, gender, and AI development", *International Journal of Design Creativity and Innovation*, Vol. 11 No.1, pp. 62-79. https://doi.org/10.1080/21650349.2022.2136762

Kwon, E., Rao, V., & Goucher-Lambert, K. (2023), "Understanding inspiration: Insights into how designers discover inspirational stimuli using an AI-enabled platform", *Design Studies*, Vol. 88, pp. 101202. https://doi.org/10.1016/j.destud.2023.101202.

Lee, YH., Chiu, CY. (2023), "The Impact of AI Text-to-Image Generator on Product Styling Design", In: Mori, H., Asahi, Y. (eds) *Human Interface and the Management of Information. HCII 2023*. Lecture Notes in Computer Science, Vol. 14015. Springer, Cham. https://doi.org/10.1007/978-3-031-35132-7_38

Li, X., Su, J., Zhang, Z., & Bai, R. (2021), "Product innovation concept generation based on deep learning and Kansei engineering", *Journal of Engineering Design*, Vol. 32 No. 10, pp. 559-589. https://doi.org/10.1080/09544828.2021.1928023

Liao, J., Hansen, P., & Chai, C. (2020), "A framework of artificial intelligence augmented design support", *Human–Computer Interaction*, Vol. 35 No. 5-6, pp. 511-544. https://doi.org/10.1080/07370024.2020.1733576

Loi, D., Wolf, C., Blomberg, J., Arar, R., & Brereton, M. (2019), "Co-designing AI Futures: Integrating AI ethics, social computing and design", In *Companion Publication of the 2019 on Designing Interactive Systems Conference 2019 Companion (DIS '19 Companion)*. Association for Computing Machinery, New York, NY, USA, pp. 381–384. https://doi.org/10.1145/3301019.3320000

Maier, T., Soria Zurita, N. F., Starkey, E., Spillane, D., Menold, J., & McComb, C. (2020), "Analyzing the characteristics of cognitive-assistant-facilitated ideation groups", In *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, Vol. 83976, pp. V008T08A046. American Society of Mechanical Engineers. https://doi.org/10.1115/DETC2020-22555

O'Halloran, B. M., Hoyle, C., Tumer, I. Y., & Stone, R. B. (2019), "The Early Design Reliability Prediction Method", *Proceedings of the ASME 2012 International Mechanical Engineering Congress and Exposition*. *Vol. 3:* Design, Materials and Manufacturing, Parts A, B, and *C*. Houston, Texas, USA. November 9–15, 2012. pp. 1765-1776. ASME. https://doi.org/10.1115/IMECE2012-89592

Paananen, V., Oppenlaender, J., & Visuri, A. (2023), "Using Text-to-Image Generation for Architectural Design Ideation", arXiv preprint arXiv:2304.10182. https://doi.org/10.48550/arXiv.2304.10182

Pena, M. L. C., Carballal, A., Rodríguez-Fernández, N., Santos, I., & Romero, J. (2021), "Artificial intelligence applied to conceptual design. A review of its use in architecture", Automation in Construction, Vol. 124, pp. 103550. https://doi.org/10.1016/j.autcon.2021.103550.

Popescu, A., and Schut, A. (2023), "Generative AI in creative design processes: a dive into possible cognitive biases", in De Sainz Molestina, D., Galluzzo, L., Rizzo, F., Spallazzo, D. (eds.), *IASDR 2023: Life-Changing Design*, pp. 9-13 October, Milan, Italy. https://doi.org/10.21606/iasdr.2023.784

Sarica, S., Song, B., Luo, J., & Wood, K. L. (2021), "Idea generation with technology semantic network" *AI EDAM*, Vol. 35 No. 3, pp. 265-283. https://doi.org/10.1017/S0890060421000020

Shneiderman, B. (2020), "Human-Centered Artificial Intelligence: Reliable, Safe & Trustworthy", *International Journal of Human-Computer Interaction*, Vol 36 No. 6, pp. 495-504. https://doi.org/10.1080/10447318.2020.1741118

Singh, D., Rajcic, N., Colton, S., & McCormack, J. (2019), "Camera obscurer: generative art for design inspiration", *In Computational Intelligence in Music, Sound, Art and Design: 8th International Conference, EvoMUSART* 2019, Held as Part of EvoStar 2019, Leipzig, Germany, April 24–26, 2019, Vol. 8, pp. 51-68. Springer International Publishing. https://doi.org/10.1007/978-3-030-16667-0_4

Sun, Y, & Münster, S. (2018), "A look at the research on design idea generation in industrial design: Literature review from 2003 to 2017", *Proceedings of the Fifth International Conference on Design Creativity*, Bath, UK, 31 January - 2 February 2018, pp. 31-38

Tang, Y. C., Huang, J. J., Yao, M. T., Wei, J., Li, W., He, Y. X., & Li, Z. J. (2019), "A review of design intelligence: progress, problems, and challenges", *Frontiers of Information Technology & Electronic Engineering*, Vol. 20 No.12, pp. 1595-1617. https://doi.org/10.1631/FITEE.1900398

Thoring, K., Huettemann, S., & Mueller, R. M. (2023), "The augmented designer: a research agenda for generative AI-enabled design", *Proceedings of the Design Society*, Vol. 3, pp. 3345-3354. https://doi.org/10.1017/pds.2023.335

Verganti, R., Vendraminelli, L., & Iansiti, M. (2020), "Innovation and design in the age of artificial intelligence", *Journal of Product Innovation Management*, Vol. 37 No. 3, pp. 212-227. https://doi.org/10.1111/jpim.12523

Wahl, J., Hutter, K., & Füller, J. (2022), "How AI-supported searches through other perspectives affect ideation outcomes" *International Journal of Innovation Management*, Vol. 26 No. 09, pp. 2240028. https://doi.org/10.1142/S136391962240028X

Wan, Q., & Lu, Z. (2023), "GANCollage: A GAN-Driven Digital Mood Board to Facilitate Ideation in Creativity Support", *In Proceedings of the 2023 ACM Designing Interactive Systems Conference*, pp. 136-146. https://doi.org/10.1145/3563657.3596072

Wang, D., & Han, J. (2023), "Exploring the impact of generative stimuli on the creativity of designers in combinational design", *Proceedings of the Design Society*, Vol. 3, pp. 1805-1814. https://doi.org/10.1017/pds.2023.181

Yüksel, N., Börklü, H. R., Sezer, H. K., & Canyurt, O. E. (2023), "Review of artificial intelligence applications in engineering design perspective", *Engineering Applications of Artificial Intelligence*, Vol. 118, pp. 105697. https://doi.org/10.1016/j.engappai.2022.105697

Yun, G., Cho, K., Jeong, Y., and Nam, T. (2022), "Ideasquares: Utilizing generative text as a source of design inspiration", in Lockton, D., Lenzi, S., Hekkert, P., Oak, A., Sádaba, J., Lloyd, P. (eds.), *DRS2022* Bilbao, 25 June - 3 July, Bilbao, Spain. https://doi.org/10.1016/j.engappai.2022.105697

Zhao, T., Yang, J., Zhang, H., & Siu, K. W. M. (2021), "Creative idea generation method based on deep learning technology", *International Journal of Technology and Design Education*, Vol. 31, pp. 421-440. https://doi.org/10.1007/s10798-019-09556-y

Zhou, C., Chai, C., Liao, J., Chen, Z., & Shi, J. (2020), "Artificial intelligence augmented design iteration support", *In 2020 13th International Symposium on Computational Intelligence and Design (ISCID)*, pp. 354-358. IEEE. https://doi.org/10.1109/ISCID51228.2020.00086

Zhu, Q., & Luo, J. (2022), "Generative design ideation: a natural language generation approach", *In International Conference on-Design Computing and Cognition*, Cham: Springer International Publishing, pp. 39-50. https://doi.org/10.1007/978-3-031-20418-0_3