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EXPLORING OPPORTUNITIES FOR ADOPTING GENERATIVE AI IN AUTOMOTIVE CONCEPTUAL DESIGN

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ABSTRACT

For AI to responsibly enable and enhance innovative design processes it is necessary to form an understanding of what processes and tools designers currently use, and why. This work employed remote interviews and an in-person workshop (respectively 8 and 6 different designers) to investigate the challenges and opportunities professional automotive designers anticipate towards generative AI tools in the conceptual design phase. The findings indicate that these designers prioritize novelty and value efficiency. Key challenges are finding relevant inspirational images and documentation due to fixation concerns. Although current AI lacks explainability, designers respect its potential to streamline design processes if its outputs can support the collaborative development of innovative automotive designs.

1. INTRODUCTION

An organization's ability to innovate is a key factor in surviving in a competitive market [1]. In technology-intensive industries like the automotive industry where technology is both a source and outcome of innovation, organizational players focus on design to differentiate themselves and achieve sustained competitive advantage [2]. Despite their expertise in developing innovative products, changing consumer preferences and regulatory standards are pressuring automotive organizations to also invest in their ability to innovate their design processes to deliver their new products with shorter turn-around times [3]. As the design process is concerned with the development of (novel) solutions to a specific set of requirements, its complex and iterative nature necessitates the collaborative effort of many people to address [4]. Thus, a range of digital design and collaboration tools have been developed to support those people and processes [5].

Recent technological developments in Artificial Intelligence (AI) and Machine Learning (ML) present an opportunity for new and existing tools to better support the design process [6]. One area in particular where designers could benefit from AI capabilities is in the early design phase consisting of the iterative activities of information gathering, idea generation, and evaluation. Despite the high uncertainty and ambiguity that characterize this conceptual design phase, decisions in this stage can significantly shape elements of the final design such as performance, reliability, cost, and safety [7]. Promising examples of Human-AI co-creation that promote creativity in the ideation phase include increasing the variety, quantity, and novelty of ideas [8], overcoming cognitive fixation and scaling up analogical innovation [9], as well as interactive sketching [10] and 3D model development [11] of automotive concepts.

Given the importance of the conceptual design phase on the quality of the final product and the efficiency of the overall process, it is particularly critical for AI-enabled design tools to involve end users in their development process. Insufficient involvement of the human element in their development can complicate technology adoption [12]. This is evidenced by the heated debates over the copyright infringements around generative AI software [13] that limit adoption, while the lack of transparency and controllability of AI tools limits their effectiveness when adopted [14]. Similarly, research work investigating how and why designers use their tools indicates that the designer-tool relationship is more complex than tool developers often assume [15, 16].

Thus, the development and adoption of technologies with such widespread implications come with benefits and risks that need to be managed so that the technology can be steered in a responsible and sustainable direction [17], especially when the demand for such developments is high.

Automotive design is one such context where the drive to innovate is high yet mistakes are costly. Automotive design is a challenging process, requiring the creation of visually appealing designs that meet practical and safety requirements while enhancing the user experience to cater to diverse needs and preferences. The industry is undergoing significant changes,

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especially with the rise of new startups and the growing demand for electric vehicles. This demand necessitates innovative design approaches, as electric vehicles differ fundamentally in power provision and consumer expectations. Designers face the task of integrating advanced driver-assistance systems, autonomous driving features, and connectivity without compromising aesthetics, functionality, and safety. The competitive market demands faster development cycles, putting even more pressure on the generation and execution of innovative ideas. Overall, automotive concept development is a time and labor-intensive process. From ideation to sketching to modeling, the process can take months to years to complete. To streamline this, designers are turning to Generative AI to automate mundane tasks, allowing them to focus more on their creative vision.

1.1 Research questions

Recent AI applications suggest that AI can both influence and accelerate organizational innovation [6]. For AI to meaningfully contribute to the iterative processes that make up the conceptual design phase, a clear understanding of the existing design tools and processes is necessary. The representation of design knowledge in computer-aided design (CAD) and styling (CAS) has been an ongoing research topic involving both the representation of design objects and design processes [18, 19]. In line with recent work that concludes that the most benefit from AI can be derived when its focus is to support and augment human creativity rather than replace it [**?**], the main purpose of this work is to investigate what opportunities and challenges designers see for AI concerning their existing design processes. Focusing on the early conceptual design phase, this work is guided by the following research questions:

1. What are the main challenges automotive designers encounter during conceptual design?
2. How do existing processes and tools support automotive conceptual design?
3. What opportunities do designers see for AI tools in conceptual design?

2. BACKGROUND

2.1 Early phase design processes

Conceptual design is often seen as the most creative yet difficult stage, with the innovative or creative outcomes of this stage contributing to an organization's competitiveness [20]. For this paper, conceptual design refers to the early phases of the design process where the solution space is at its most indeterminate and fluid, and the focus is more on the discovery and divergence of ideas. At this stage, designers are concerned with identifying and articulating the desired function and form. In the case of commercial automotive design, the overall product type may have already been determined (e.g. two-door convertible or hatchback), leaving the steps around idea generation, evaluation, and concretization as the core activities in conceptual design [21]. A well-researched concern in this early phase is the risk of design fixation, where a designer may be unwilling or unable to generate multiple solutions to a given problem and impede creativity [22]. Researchers have spent much effort studying how design fixation impacts creative problem-solving in design (see [23] and [24]). Designers have also developed strategies to overcome design fixation [25], including drawing inspiration from a wide range of sources [26] and other domains [27, 28]. Personalized strategies may play an important role as well, as images that are inspirational to some designers may be fixating to others [29].

2.2 Human-AI collaborative design tools

Given the importance of creativity, inspiration, and fixation on the novelty of a design outcome, there is much interest in developing tools and processes to aid the conceptual design phase. Early tools explored providing support to novice designers through a digital repository [30]. More novel technologies such as Extended Reality (XR) have been explored as a means to mitigate design fixation [31]. The focus of this study is on generative AI technology, referring to a process by which a training database is used to generate new content, typically through explicit programming or implicit learning (for an overview of common methods and tools see [32]. Based on this premise that the design process can be quantified and formalized, some tools employ computational algorithms to generate and evaluate concepts. For example, Bryant et al. [33] have developed a concept generation algorithm that leverages existing component knowledge to produce multiple design concepts, while Goucher-Lambert et al. [34] investigated the use of inspirational stimuli on design solutions. Where technological capability was lacking in the past, recent developments in high-performance computing and increased data storage capacities have enabled the potential of AI technologies to rapidly increase. In particular, tools and situations where AI is employed as a tool or collaborative assistant are promising [35]. In creative industries, AI technologies can be grouped into one or more of the following five categories: "(i) content creation: where AI is employed to generate original work, (ii) information analysis: where statistics of data are used to improve productivity, (iii) content enhancement and post production processes: used to improve quality of creative work, (iv) information extraction and enhancement: where AI assists in interpretation, clarifies semantic meaning, and creates new ways to exhibit hidden information, and (v) data compression: where AI helps reduce the size of the data while preserving its quality." [**?**]. In addition to research on the technical capabilities of such AI-enabled tools, it is necessary to gain insight into the perspective of their intended users. This is particularly important for generative AI, which has spurred discussion and debate over its implication on creativity [36] and society [37]. The importance of modeling the design process has been long acknowledged by researchers in the AI space [18].

3. METHOD

This paper explores what challenges and opportunities designers foresee when implementing generative AI to augment their existing design processes and how they conceptualize possible future designer-AI interactions. The investigation consisted of two rounds. In the first round conducted in Fall 2022, remote semi-structured interviews were conducted with 8

designers (2 designers per team, 4 teams in total) to map their existing design processes and identify potential opportunities for generative AI. The individual format of the interviews enabled the designers to provide deeper insight into their personal processes and tool usage. In the second round conducted in Spring 2023, 6 designers from the same organization (5 new designers, 1 who also participated in the remote interviews) participated in a follow-up in-person workshop. In this interactive group session, designers explored what one such previously identified designer-AI interaction might look like in more detail and in a format that more closely resembles their daily practice. The following sections describe the methodological details of this study.

3.1 Remote semi-structured interviews

To understand what the designers' existing design processes look like and why, 8 designers (2 each from 4 design teams) were interviewed for approximately 60 minutes. The virtual interview followed a semi-structured format to allow for a deeper exploration of topics raised by the interviewee. A pre-interview document was shared with the interviewees to support the interview. The pre-interview document briefly explained the goal of the study, terminology that may be used, example interview questions, and examples of materials we might ask them to share. Prior to the interviews, a pilot study was conducted with a representative from the organization who was very familiar with their design process. This enabled the researchers to gain a basic understanding of the design process and ask more targeted questions during the interview itself. The interview questions were designed to gather comprehensive insights and consisted of a series of open-ended questions and prompts that allowed participants to share their experiences, opinions, and suggestions related to generative AI. The protocol was also discussed with team members who are AI and HCI subject matter experts to ensure the questions would capture essential aspects of the research questions. These semi-structured interviews lasted around 60 minutes in which the following topics were discussed: - Their current design process: what activities they perform, when and how they do them, what tools they use, examples of how their work looks throughout, and which activities are more challenging and time-consuming. - What the design space looks like: how much do they focus on coming up with new and different designs, what requirements their designs need to adhere to, how much influence they have on those requirements, and how ideas are selected for further development. - How they feel about AI tools: which activities might be supported by AI and what a human-AI interaction might look like.

3.2 In-person design challenge

To explore designer-AI interaction, a design challenge was created and structured as a series of in-person design activities that were run as part of a larger three-day workshop around AI tools for designers. The workshop participants consisted of 6 different designers representing 3 different teams from the organization. The designers had between 1-10 years of experience working either at the organization or in the design field. The design activities were centered around the hypothetical design challenge to "Design a vehicle that can transport humans in a zombie apocalypse from Busan to Seoul". Each activity lasted around 25 minutes, was designed to build upon the previous stage, and was followed by a group discussion to ensure sufficient time for participants to deeply engage, reflect, and share their thoughts on the material. The activities were: 1) generate as many concepts as possible, then 2) select up to three concepts to move forward with, and 3) refine one concept. For the reflection, designers were asked to present their ideas to the group and provide their thoughts and feelings about the process they used to arrive at those ideas.

Data was collected primarily through researcher note-taking of participant observations and the collection of artifacts generated during the workshop, such as the sketches and Mural boards created by the participants, and their responses to the survey.

3.2.1 Procedure. To address the design challenge, the designers were grouped into two teams of three. During each design activity, one designer was asked to play as the AI while the remaining two acted as human designers. The "AI" was the only one with an internet-connected laptop and access to the online collaborative whiteboard tool Mural. Figures 1 and 2 respectively depict what Team 1 and Team 2 created during each phase. In the first phase of concept generation, designers looked for inspirational images that evoked feelings of wheels that move quietly (Team 1) or efficiently (Team 2). In the subsequent concept development and refinement phases, these inspirational ideas were translated into rough automotive concepts, and then more refined concepts of enlarged, rugged wheels with grooves (Team 1) or series of wheels similar to a military tank (Team 2).

After each activity, designers were asked to rotate their roles so everyone had a chance to play as the AI. Both human and "AI" designers could create "magic wands" to create desired features and results. These magic wands provide insight into what the designers would wish for to complete their tasks.

To more closely resemble existing interaction styles between AI and designers, the interaction between the AI and designers was asked to be through notes and sketches. This was supported by the linguistic differences between the researcher and the designers, which "forced" more limited communication.

The design exercise concluded with a group reflection activity. Participants were asked to respond to survey questions through a live interactive polling tool (Mentimeter) and their answers were displayed in real-time on a projector screen. Once all participants had responded, they were then prompted to engage in a verbal reflection discussing both their own and others' survey responses.

4. FINDINGS

4.1 What are the main challenges that automotive designers encounter during conceptual design?

4.1.1 Need for novelty. Tasked with developing novel solutions that meet technical requirements, the automotive designers in this study consider their ability to find relevant inspiration and translate it into interesting design concepts key to their success. They were particularly focused on developing *novel* design concepts. As such, they were primarily concerned with finding relevant inspiration that they could use to create

FIGURE 1: Images of Team 1's ideation as they went through the concept generation, development, and refinement phases to develop a thick and grooved wheel.

FIGURE 2: Images of Team 2's ideation as they went through the concept generation, development, and refinement phases to develop an efficient and quiet wheel.

new and interesting design concepts. They know they have done well when their design is selected for further development and refinement during the design review meetings. When this happens, the presenting designer becomes the key designer for that project. Because the designers are motivated by seeing their design vision come to life, being selected for manufacturing is considered the most visible form of acknowledgment for the designer's time, energy, and effort. Conversely, it is hard when their designs are not selected. Because of the large number of designs that are generated and presented, inevitably many will not be selected. The disproportionate difference between the number of designs that are generated and those that are selected is visualized in Figure 3. Designers generate many design concepts and initial sketches to visualize those concepts, often going back and forth between the two activities before settling on one design concept and sketch that is presented for consideration at the design review. Once an initial sketch has been presented, it is no longer considered novel, regardless of whether it was selected for manufacturing or not. Therefore, those unselected sketches are discarded and the designer either starts over again with a new design or joins other projects as a supporting designer.

4.1.2 Fear of fixation. The majority of the designers' efforts are spent on looking for inspirational images. When asked what the designers do with the inspirational images that have been used to create concept images, most designers indicate that they do not spend much effort on documenting or otherwise archiving inspirational images or other design artifacts. While some designers create personalized ways of storing inspirational images and generated sketches, there are few coordinated documentation processes in place. The designers mention several barriers around documentation. The main deterrent the designers mention is the risk of past work increasing fixation, something they try to avoid

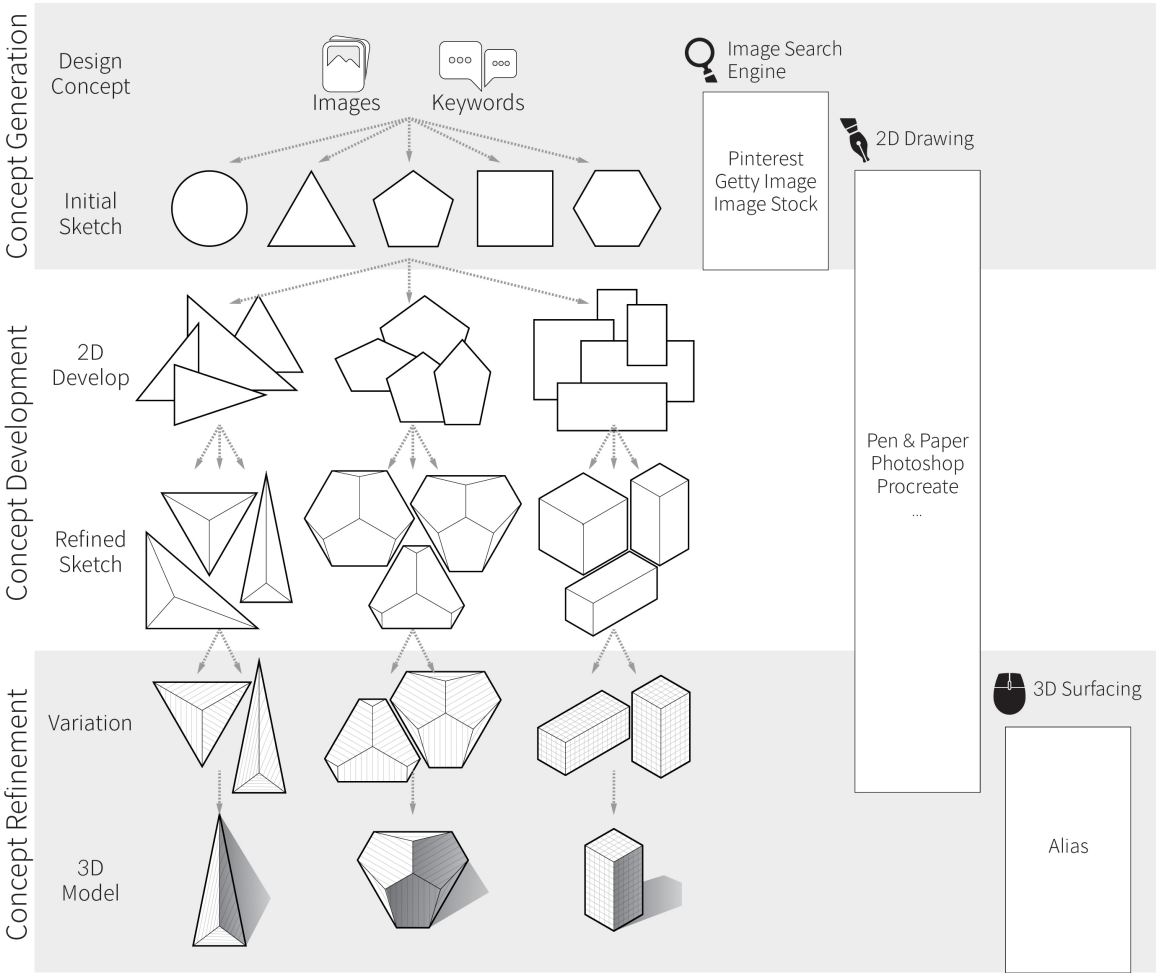

FIGURE 3: Schematic overview of the main tools used in each design phase. While the process is depicted as linear, in reality, the processes and tool usage are more fluid.

as much as possible. The designers explain that once a concept has been presented, it is not considered novel anymore, regardless of whether it was selected or not. Because previously presented designs are no longer usable, the designers believe that there is no value in keeping a record of that concept. Although it is unclear whether this reasoning is the cause of their behavior, an artifact of the automotive design process, or a justification in reflection, there is no systematic documentation of past work. As part of their ideation process, designers will generate many ideas in their search for the best idea in the form of rough sketches, thumbnail sketches, 3D models, and mockups. Additionally, there is a large quantity and variety of generated content due to the large number of designers who can participate in the process of coming up with ideas. This results in a large number of generated ideas and sketches, of which only a tiny subset makes it through the selection process. This makes it difficult for designers to decide which content is relevant to document.

The lack of documentation of inspiration and design concepts extends to a lack of documentation around feedback. Because feedback is very valuable to the design process and its outcome, the designers frequently request and provide feedback on design concepts and sketches. Barriers to documenting feedback relate to the effort required to document it. Firstly, feedback is often fairly easy to implement, or there are only changes between versions, like when most of the design was approved, so tracking the feedback does not feel necessary as it becomes obsolete once implemented. Secondly, feedback can come from different places and in different formats, such as from teammates, managers, or colleagues from other teams/departments, who can provide feedback through spoken and written text or images. Due to the shared understanding between designers, it can also be difficult to document feedback in a concise and meaningful way. For example, a request to “simplify the design”, “keep the original concept more in mind”, or “this line doesn’t feel right” is difficult to interpret without context. Additionally, the designers need to express domain-specific language, such as the A-line (the line running over the car describing its silhouette) and the Dash-to-Axle ratio (distance between front wheel centers and the windshield base).

4.2 How do existing processes and tools support automotive conceptual design?

Designers are involved as early as possible in new projects to provide input into concept generation, and they employ several

strategies to maximize novelty in their conceptual designs.

4.2.1 Looking for inspiration through visual search engines. When it comes to creating design concepts, they employ two approaches in varying degrees. In the first approach, they try to identify new or interesting ideas by starting from a theoretical concept, thought experiment, feeling, or interesting image and exploring it from various angles or through unusual associations. In the second approach, designers iteratively work towards an unexpectedly interesting execution that best brings out the strongest feeling of a particular concept by exploring a trail of different but related keywords while keeping the overall concept in mind. In both approaches, designers often turn towards visual image search engines or repositories, such as Pinterest, Google, or Dribble. Offline sources like magazines and museums are used whenever possible as well. The designers are continuously looking for new and surprising things they have not seen or experienced before so that they can take the most interesting ideas from other domains and apply them in new ways in their own automotive design context. The designers have created personalized, informal strategies to identify suitable inspirational images. These strategies range from looking at images without any predetermined notions in mind of what a good solution might look like and searching for anything that evokes thoughts and feelings of something new and interesting, to employing a guided approach to identifying and translating relevant inspiration into a viable design concept. In the latter case, designers move back and forth between keywords and images to explore images and concepts that inspire them. The synergy between processes and tools is exemplified by the popularity of Pinterest among designers. This tool works well with the designers' processes due to its user-friendly search functionality that allows for the exploration of adjectives and keywords that are closely related. Additionally, the ease of idea sharing and collection facilitates the discovery of creative inspiration.

4.2.2 Leveraging collaboration and competition. The designers aim for a design concept that is both novel and viable. When developing their design concepts, the designers first focus on visualizing a strong concept. The focus of the designers is initially more on developing a strong design concept than adhering to technical requirements, which is the focus of the engineering team. The collaboration with the engineering team mimics this closeness, with collaboration efforts gradually increasing as they need to work together more to resolve technical requirements. This process takes a long time, from several weeks to months. For example, when the design concept is sketched out in 2D, it lacks detailed specifications such as the exact dimensions or angles of a curve because they are not yet relevant at that stage. However, when translating the 2D image to a 3D model these details do become important and require regular back-and-forth communication with the engineering team to ensure the agreed upon design concept is honored while meeting the required technical specifications.

While the majority of the design process is highly collaborative, the first phase of concept development contains competitive elements to encourage more innovative designs. Any designer may propose a design concept for consideration, regardless of which team or department they are from. Thus, the creative portion of the concept generation process is highly individualized, while the refinement portion is largely collaborative with designers regularly and explicitly seeking input and feedback from other designers and managers. To maximize the effectiveness of their individual and team processes, the designers are free to utilize the tools that best suit their processes. While design tools are versatile and could be used for different activities, designers gravitate towards specialized tools to fulfill specific needs (see Figure 3. For example, in the conceptual design phase, designers mainly use visual search engines and 2D drawing tools like Pinterest, Pen and Paper, and Photoshop to search for inspiration and sketch ideas. The designers describe that Pinterest is a popular tool when exploring the internet for inspiration because it is easy to search with adjective keywords that are directly related to the concepts. Unlike generic image search engines, Pinterest's focus on sharing and collecting images and ideas makes it well-suited to facilitate the discovery of inspiration for concept generation. When visualizing ideas, some designers prefer to spend more time in the 2D sketching stage, while others prefer 3D models and may start directly in Alias.

4.3 What opportunities do designers see for AI tools in conceptual design?

To explore what a useful AI tool might do, regardless of whether it is currently technically possible or feasible, the designers were asked variations of the question: "If there was a magic wand or button you could press that would help you in your design process, what would you like it to do?" The following section discusses several of the magic wands the designers suggested. This question was asked in both the survey and the workshops. Although designers were more familiar with different AI tools in the workshop (as it took place after the boom of AI design tools like Dall-E and Midjourney), the themes and needs expressed by the designers were similar in that they were primarily looking for ways to a) increase their creativity (section 4.3.1), or b) increase their efficiency (section 4.3.2).

4.3.1 Supporting creativity. The designers' desire for novelty drives the why and how behind their tool usage. One particular challenge that the designers face in finding inspiration on visual search engines is that everyone who uses the same tool and the same keywords is likely to see the same images. Search algorithms are trained to find trends, patterns, and commonalities in data. However, designers are interested in unusual, unique, or rare instances to spark their creativity. They have not yet found a reliable way to indicate which part of a provided image or keyword the designer is most interested in exploring, or how different the desired search result should be from the provided input. Although diversity and heterogeneity are emphasized in the early stages of conceptual design, in later stages designers would like to see variations of a more constrained space that is the already mostly defined concept. From a technical standpoint, these two desires are antithetical, with the former emphasizing high deviation from the base image while the latter emphasizes high similarity from the base image.

4.3.2 Supporting efficiency. In the existing process, the majority of the design process results in the creation of 2D images and concepts. Once the 2D image of the design concept has been refined and approved, the concept is then converted into a 3D model. One of the biggest pain points in this translation process is that images that look great in a 2D shape do not translate well into a 3D shape, thus requiring designers to go back and forth to make changes to the already approved images. This process of making new concepts, incorporating them, and redesigning the 3D model takes time and effort that could rather be spent on something else. During the workshop, the designers created a magic wand that enabled them to create a 3D preview of what that finalized 2D design could look like as a 3D model, or assist in the process of translating 2D sketches to detailed 3D models. The designers who have played around with similar tools mention that even though the actual images made sense, the 3D modeling data itself was inadequate (as in, lacking sufficient shape or structure to build on). In both cases, the main purpose of the AI tool would reduce time and effort by enabling them to evaluate the viability of a concept much earlier in the process, something that they would normally only discover at the end of the process when the concept has gone through the whole design process.

While time savings are important, the designers value the ability to visualize their intent or to communicate their vision behind a concept. When translating 2D sketches to 3D models, the designers spend a lot of time and energy on translating the feeling of the design concept. The designers indicate that a common response when people see their 3D models is that they say "Oh, this doesn't quite look how I imagined it would look based on the sketch". Some designers think that an AI tool that would enable them to directly work in 3D (e.g. skipping the 2D sketching phase) could be valuable if it can visualize the designers' intent or the vision behind the concept in sufficient detail. Determining what output quality constitutes as sufficient detail depends on whether the designers are looking more for a concept preview versus a more efficient transition from a 2D concept to 3D model, with the former requiring less precision and polish than the latter. The designers believe that using AI to streamline this 2D to 3D translation process will reduce time sinks and enable them to focus more time and energy on the ideation and development of new and interesting ideas, the part of the ideation process that many enjoy the most.

5. DISCUSSION

5.1 Summary

Design tools support designers and their design processes. While AI can accelerate the design process by enabling and enhancing innovative design processes [32], AI tools need to be integrated into existing design processes to leverage this potential. Focusing on the conceptual design phase, this work explored what tools and processes professional designers in the automotive industry currently use, how they describe their main challenges, and what opportunities they see for generative AI tools. Analysis of the remote interviews and the in-person workshop revealed the following key findings.

The main challenges designers face in the conceptual design phase were found to be the difficulty of finding interesting inspirational images and overcoming the risk of fixation when developing novel design concepts. While the use of image search engines can be expected, the way that the designers use these engines is more nuanced. The designers are intentionally looking for images that are unique, unusual, or otherwise stand out from the crowd. This is the opposite of how most algorithms operate, which typically aim to find trends and commonalities. Thus, finding inspiration when everyone is shown the same popular images can be challenging. The majority of designers' efforts go towards finding inspirational images, yet little effort is spent on the documentation of design artefacts (e.g. inspiration, concepts, or feedback). The designers are wary of anything that might introduce fixation or otherwise impede their creativity because novelty is such a high priority. To them, the time and effort lost by figuratively (and sometimes literally) re-inventing the wheel is considered a lesser problem than the potential fixation caused by exposure to pre-existing designs. Even if documentation was desired, the large quantity and variety of generated design concepts, uncertainty around which artifacts are relevant to document, and the difficulty of documenting design rationale concisely and meaningfully contribute to the perceived effort of documentation outweighing potential benefits.

Regarding their existing tools and processes, designers are involved as early as possible in concept generation, and early-stage competition is used to stimulate innovation. The designers were found to rely heavily on visual search engines to iteratively explore ideas to identify new or interesting concepts from other domains that they can apply in an automotive design context. Designers initially focus on strong concepts over technical requirements, leveraging cross-functional collaboration with engineering to refine ideas once a design concept has been determined. Converting a design concept from 2D to 3D can take several weeks or months to get right, as it is difficult to translate details.

Overall, the designers view AI as another tool that could be added or integrated into their existing tools and processes if it supports their ability to be more creative and more efficient. They express the hope that more efficient design processes would enable them to focus more on the development of creative ideas. These processes can be related to each other if, for example, an AI tool could quickly generate many variations to a designer-provided design then that would help the designer generate more creative concepts at a higher speed. Such designer-AI collaboration would require effective communication between the two, particularly around the expression and understanding of intent. The justification or rationale behind a design is necessary for designers to communicate with each other and make design decisions. Current AI tools are too much of a black box to provide such necessary explanations. AI could also speed up the process of visualizing design concepts by streamlining the conversion between 2D and 3D designs, which would support the designers' ability to quickly explore design visions.

5.2 Implications for AI tool development

5.2.1 Input agnostic search. The designers are open to a variety of media when searching for inspiration, and expressed a desire to combine those different input types to fuel their

inspiration search. For example, it is possible to search the internet using a text or image prompt. In many tools, these are separate functionalities. But designers are visual thinkers, so for them there is a tighter connection between text and images. This became clear during the workshop when designers used images in addition to text input to better express their intentions. At the same time, the textual input could refer to very specific things. The designers explained that many keywords are associated with a specific concept or shape. For example, the keyword "organic" is associated with shapes that are more irregular, smooth, and fluid, while the keyword "modern" could refer to a specific art style (e.g. modern vs. classical art movements) or time (e.g. pre-2000s vs. post-2000s). These observations were linked to some of the difficulties the designers encountered during the in-person design challenge when attempting to effectively communicate with an AI tool. This communication difficulty applied both ways and centered around expressing and understanding intent. When communicating their intentions to the AI, designers are unsure about how the AI interprets their text and image input, and subsequently, whether they are in alignment about what is needed. To some extent, this can be mediated through the development of domain-specific dictionaries. For example, certain words are tied to specific shapes and meanings, while others could be interpreted more freely. When interpreting images, the designers were curious to understand the choices that the AI made and expressed a desire for the AI to provide some form of explanation behind their design.

5.2.2 Output variety. Some designers indicate that the process of coming up with variations of an accepted design can be tedious, especially when such variations are minor. It could be an opportunity for AI tools to generate specific solutions that are related to designer-provided input. For example, if the designer could provide an accepted sketch, then the AI could suggest variations based on that sketch that the designer can then evaluate for relevancy or appropriateness to their intentions. Such variations could be large and diverse, or minor and narrowly confined depending on the design phase. In the early stages of searching for inspiration, the designers are wary of fixation and images that are too similar to existing designs. Here, the AI tool serves as a means to encourage divergent thinking and broadening of the vaguely defined solution space. When generating diverse images, the designers are hoping that the AI tool generates something unexpected, crazy, or unique like “something a human could not make” or “something I’ve never seen before”. Even weird shapes can be desirable if they provide the designers with a starting point that they can turn then into a usable design concept. In the later phases when the general design concept has already been determined and the designer is working on refining the concept, such variations may be smaller to respect the now mostly defined solution space. Examples of narrower variations would be the same image from different angles, or image elements visualized in different styles or colors.

5.3 Limitations and future work

To appropriately scope the contributions of this study, we offer several limitations that should be considered when interpreting the broader applicability and generalizability of these results. Firstly, one of the strengths of this work is the deep, contextually rich investigation into the design processes of practicing designers. As the participants are from the same organization, there may be limits to the generalizability of their processes, tools, and project requirements to other design teams in non-automotive industries. To balance the selection of expert designers with a wider range of perspectives, recruitment efforts were targeted both at multiple designers within the same team and designers from different teams. This diversity of participants contributes to a wider representation of viewpoints and experiences of design processes. By describing the specific design processes in detail, the applicability of the findings to other contexts can be more easily assessed. For example, the overall design process may apply to designers in other industries, while the emphasis on keywords to shape the early concept generation and the close interaction between designers and engineers in the modeling phase may be more unique to the automotive context. Secondly, although concerns around perpetuating biases, incorrect outputs, copyright violations, and strain on environmental resources are salient concerns that could affect AI adoption [17], the designers in this study did not explicitly mention any of these. As investigating such concerns was beyond the scope of this work, it remains unclear to what extent these concerns matter to practicing designers. In line with previous work, this study did find that current AI systems provide little explanation about their workings, making it difficult for users to understand the AI’s behavior [17]. Lastly, the automotive industry is highly competitive, and innovation is considered one of the key differentiators in the market. Thus, certain elements have been omitted to respect non-disclosure agreements. The information presented in this paper sought to strike a balance between providing sufficient insight without compromising confidentiality requirements. Additionally, this study was conducted just before the AI boom of 2023. Illustrative of the rapid progress of AI tools, ongoing research by the authors in this research direction indicates that the designers are experimental in their adoption of AI tools and both users and tools become more sophisticated as their interaction continues.

6. CONCLUSION

The rise of AI is anticipated to change existing design processes by enabling and enhancing innovation capabilities [6]. The competitive nature of the automotive design context is particularly sensitive to these developments. The pressure to innovate automotive design and functionality is tempered by the need to maintain practical and safety requirements. To meet these needs, designers are increasingly experimenting with Generative AI to support their design processes.

The findings of this study provide insight into the automotive design processes as they currently exist, and offer challenges and opportunities for AI-enabled design tools. While the public familiarity with AI took off during this study, the study findings describe the designers’ functional needs that apply regardless of the specific tools that they currently use or may use in the future. In their interaction with AI, the designers are actively driving and guiding the design direction. They are intentional, critical, and specific in their usage and place higher demands

on the output quality than more casual or non-automotive users might. For example, they desire precise and specific control over the AI output, and the output needs to be (re)usable in their processes. The designers in this study view AI as another tool that can be integrated into their existing tools and processes. Although the designers believe that creativity is about the designer's personal expression and the combination of existing ideas in a new way, they highlighted that AI could make their creative process more efficient by generating variety and combining concepts in unexpected ways. While not identified as a challenge by the designers, the researchers encountered a lack of documentation that was unexpected, as knowledge management is a common practice among organizations and creatives. The designers attributed the lack of systematic documentation to a fear of fixation and emphasis on novelty. For the designers in this study, the trade-off of spending more time figuratively (and sometimes literally) reinventing the wheel is an acceptable risk to avoid fixation. However, for AI tools the documentation of successful or acceptable designs versus unacceptable designs will be necessary as the quality of AI output is tied to their input and training data. The development of high-quality datasets will be needed for AI tools to become more widely integrated into design systems and deliver on their potential of increasing efficiency and creativity. While the potential of AI and AI-enabled tools is significant, the findings of this work hope to contribute to the responsible development of AI systems that augment human creativity and capability.

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