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School of Architecture

College of Fine Arts

Thesis

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TITLE:
Generative Image AI for Design

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Abstract

Generative image AI tools have sparked heated discussion in the creative community. How generative visual AI can be used for the design community is understudied. From pilot studies and early explorations, we found that designers find image AI an excellent channel for inspiration search in the early design stage. Using a design sketch as the input could significantly reduce the uncertainty of the outcome. Moreover, the fast representation and high fidelity characteristic of diffusion models' outcome may help bridge early-stage design communication. Based on these pilot study insights, I conducted two studies followed by the interview session. In study 1, I recruited designer participants and conducted a design sketch-AI collaborative workflow study. In study 2, I recruited designer and client participants and conducted a remote design study with designer-client participant pairs. Study 1 characterized image AI - design sketch collaborative workflow. Study 2 portrayed image AI-supported design communication. Study 1 provides insights about what image AI can or cannot do for design practice; the challenges designers encounter while working with diffusion models, and the improvement directions for image AI to serve as better design tools. Study 2 profiled image AI as a resource for bridging design communication and provided insights for future image AI system construction for bridging design communication.

Keywords: Text-to-image, design, generative AI, creativity support, communication, CSCW

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Glossary

Diffusion models: In machine learning, diffusion models, also known as diffusion probabilistic models, are a class of latent variable models. They are Markov chains trained using variational inference ("Diffusion Model," 2023).

Prompt engineering: the formal search for prompts that retrieve desired outcomes from language models, where what is desirable is dependent upon the end user (Liu & Chilton, 2022).

Generative image AI: the use of artificial intelligence algorithms to generate new, previously unseen images that mimic the characteristics and patterns of a given dataset. (ChatGPT, personal communication, 2023)

1. Introduction

Generative AI is revolutionizing the creative community. The growing competence of Machine Learning and Artificial Intelligence infilled the creative community with unparalleled possibilities. From text-to-image to paragraph-to-video, generative AI tools make content creation easier, even for laypersons who never had professional training. They not only "lower the floor" for laypeople to create content but "heighten the ceilings" for professionals (*HCII Seminar Series - Steven Dow | Human-Computer Interaction Institute*, n.d.).

Narrowing the scope down to **generative image AI**, VAE, and GAN to diffusion models is a huge leap in generative image AI performance. It also brings about debates regarding copyright infringement, improper content, and a lack of originality (Shaffi, 2023; *This Artist Is Dominating AI-Generated Art. And He's Not Happy About It.*, n.d.). Recent research about image AI is around developing design guidelines for prompt engineering (Liu & Chilton, 2022), exploring the image AI-mediated drawing conversation (Yurman & Reddy, 2022), developing principles for designing generative AI applications (Weisz et al., 2023) and utilizing image AI to inform 3d sculpture design (Smith et al., 2023). Recently, researchers in HCI have been exploring the broader application and collaboration pattern incorporating image AI for unleashing creativity (Muller et al., 2023). Though the studies around image AI for art is popular, how image AI can be a resource for design practice is understudied. But I see image AI has huge potential for design practice. Personally, I'm interested in channeling image AI's competency to the design community and empowering design practitioners.

My research discusses generative image AI as a resource for the design community. Is it feasible for designers to benefit from image AI, especially in the early stage design process (I define the early stage of design as the stage where the designer hasn't set a design plan to go and started proceeding to professional modeling/rendering software for design execution)? How could designers use those tools in their routine practice? Could image AI facilitate design communication? Those questions emerge in my brain, and that's the starting point of my thesis. In the Fall 2022 semester, I duplicated a pipeline shared by Andy Xor (*4.2 Gigabytes, Or*, n.d.), and I was amazed by the outcome AI generated even if I gave so little input (see Image 1). Thus, I conducted two studies exploring the potential of image AI for design with the following questions.

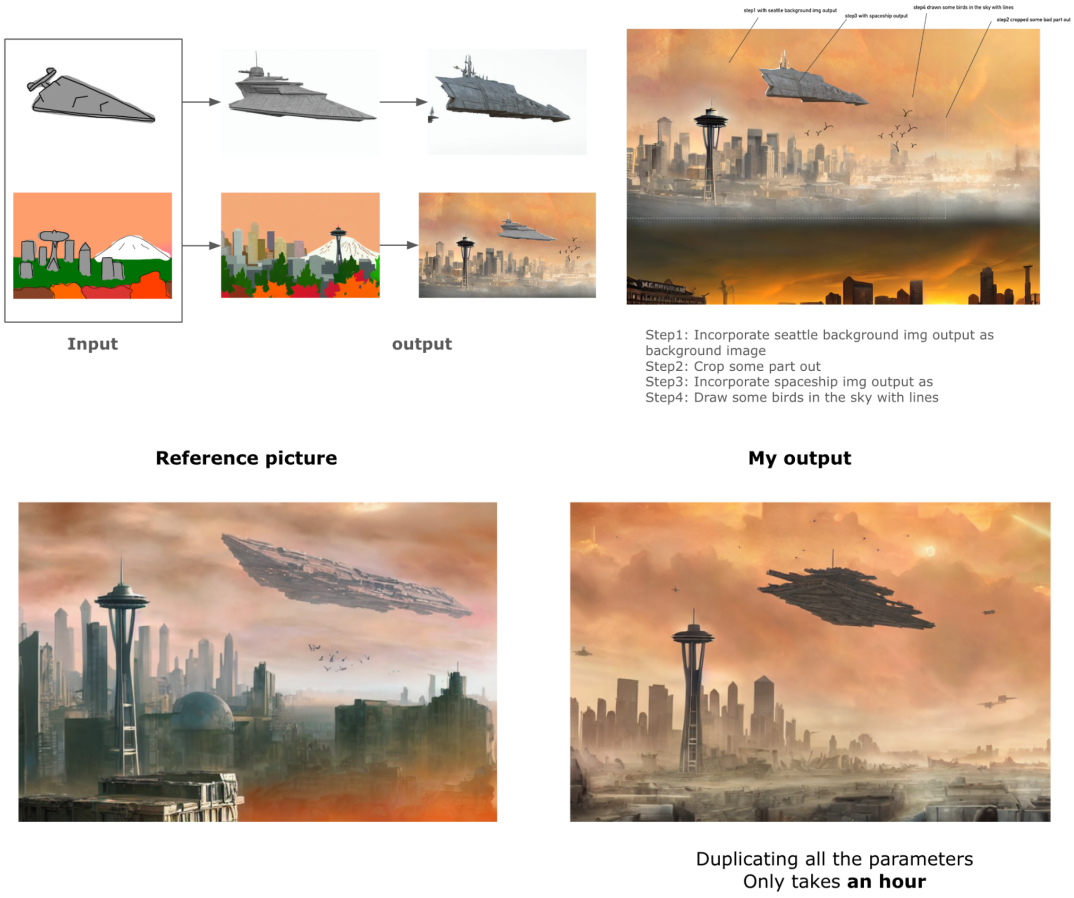


Image 1: Top: The processes of an hour's work duplicating Andy's pipeline.
Down: Comparison between the reference picture of the artist[1]
(Source: https://andys.page/posts/how-to-draw/) and my output.

1.1. Research Questions and Summary of Approach

My research is around answering the following questions:

a. *How do Architects use **design sketching** workflow in compensation with generative image AI for early-stage design?*
I conducted studies with the designer participants. I assigned a design task and let the designer explore this collaborative workflow on iPad Procreate software and the DreamStudio website[2] that runs the stable diffusion algorithms.

b. *How do Architects and clients use generative image AI to facilitate **synchronous design communication** in early-stage design processes?*

[1] 4.2 Gigabytes, or: How to Draw Anything https://andys.page/posts/how-to-draw/
[2] DreamStudio https://beta.dreamstudio.ai/generate

I conducted the study with both designer-participant and client-participant. I assigned a design task to the participant and conducted a design session using image AI, Figma board, and Zoom for bridging design communication and sharing design ideas.

In summary, I carried out a one-year-long study. For Fall 2022, I conducted pilot studies and found interesting research questions and hypotheses. For Spring 2023, I conducted research based on two research questions to inform future system design and development by channeling the generative model's full potential for augmenting design capabilities.

1.2. Contributions

This thesis makes the following contributions:

a. Portraying design sketches in combination with generative image AI in design workflow and providing insights for guiding the future sketch-based system design.
b. Characterizing generative image AI tools' affordance in remote design communication between clients and designers.

1.3. Thesis Structure

In Chapter 2, I framed the theoretical background for my research, including pilot studies findings that guide the research question and the relation between the two studies. Chapter 3 is about the pilot study and early-stage explorations that helped me frame the research questions. Based on the pilot study findings, I started the research study design. Chapter 4 discusses the research exploring design sketch-image AI collaboration and relating findings. Chapter 5 is about the research using image AI for bridging design communication. In the last two chapters, I shared the overall discussion, conclusions and my future work.

2. Background

2.1. Generative models for design support

Generative models have sparked heated discussion as a source for generating creative content (Muller et al., 2023). They require little effort in inputting prompts but could provide many directions for creative exploration. For instance, generating creative writing suggestions (Lee et al., 2022), generating graphic design like advertising posters (Guo et al., 2021) and news illustration (Liu et al., 2022), generating new UI design (Huang et al., 2021; Swearngin et al., 2020; Zhao et al., 2021), etc. Researchers also chartered a clear timeline for generative AI (*✨ UPDATED - The Generative AI Timeline ✨ | Data Science and Machine Learning*, n.d.).

In the 3D design domain, the high performance of generative image AI proved the efficiency of the generative model in achieving the high-fidelity design outcome, but at the moment, the results are only

limited to 2D. One main barrier to high-performance generative **3D design** is a lack of high-quality large 3D datasets and the computation power required to achieve satisfactory outcomes. GET3D (Gao et al., 2022) model's performance on generative 3D textured meshes is impressive. However, it's still far from the quality for the product and architecture design domain that requires the high-accuracy Non-uniform rational B-spline (NURBS) that has been widely used in 3D modeling to guide the following manufacturing and building purposes. For the game industry, it's feasible, and the automation processes improve efficiency. But for industrial purpose models, there is still a huge gap between ML's competency and the desired design results.

Stepping one step back, recent researchers have been exploring utilizing image AI to inform 3D design practice (Smith et al., 2023). And in the Architecture design domain, there is already some practice utilizing image AI to inform the 3D design. Starting from the shape grammar (Stiny, G. 1980), Architecture is a domain that has a long history and utilizes generative models to inform its practice. Compared with other 3d design domains, Architecture design has to consider many constraints. Including the form, materials, culture, etc. This makes Architecture a domain I focus on.

2.2. Generative image AI platform sorting

I started by exploring on-the-shelf generative image models. Apart from the large models (LMs) that leverage the advantage of humongous training data, platforms exist for more niche design tasks. There are not only all-encompassing models Midjourney[3], Dall-E 2[4], Deep Dream[5], and DreamStudio[6] but also some domain-specific generative tools like Tattoo AI[7] and Interior AI[8] that targets a niche design domain. There exists a tension between the competency of all-encompassing models' generalizability and the small model's professionality: all-encompassing models like Dall-E 2 is great for various design and artworks, but it's not professional in a single domain. While Interior AI is professional at interior design, it can only generate interiors. Some products like NightCafe and DreamStudio seem different, but they both run the Stable Diffusion model. Besides using only text as input, Interior AI can support the user's interior image upload and provide customized interior design renderings based on the input. One commonality between platforms is they only support individual users' generations. One account user can only see their own generated images, while on the Deep Dream website, creators can see other people's artwork and their related prompts. This interested me in exploring collaboration in image generation and inspired my research question 2.

Some more advanced features like masking and auto-selection (inputting one word and automatically selecting that area for further generation) are currently in collab notebooks. After testing those platforms, I selected DreamStudio for my study. Not only because it generates aesthetically good-looking results but also because it supports version control (I selected Stable Diffusion v1.5 for the diffusion model) and image upload.

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[3] Midjourney https://www.midjourney.com/home/
[4] Dall-E 2 https://openai.com/dall-e-2/
[5] Deep Dream https://deepdreamgenerator.com/
[6] DreamStudio https://beta.dreamstudio.ai/dream
[7] Tattoo AI https://www.tattoosai.com/
[8] Interior AI https://interiorai.com/

2.3. Prompt engineering as a skill

The skill set designers need shifts while using image AI. One skill that's vital for the outcome is prompt engineering. Prompt engineering is the formal search for prompts that retrieve desired outcomes from language models, where what is desirable depends on the end user (Liu & Chilton, 2022). It is a skill that requires a certain level of expertise to frame the language within that niche design domain.

Currently, the image AI community uses official prompt guidebooks (read, 2022), reverse prompt engineering using images to retrieve the best prompt (Gal et al., 2022) and crowdsourcing to fine-tune the right prompt. Reverse prompt engineering provides a source for designers to enter the product name first and check the related generated pictures. Using websites like Lexica (see Image 2), By probing into the desired picture, the user could check the prompt used for describing that picture and thus gain the knowledge of describing the desired product with the proper prompt.

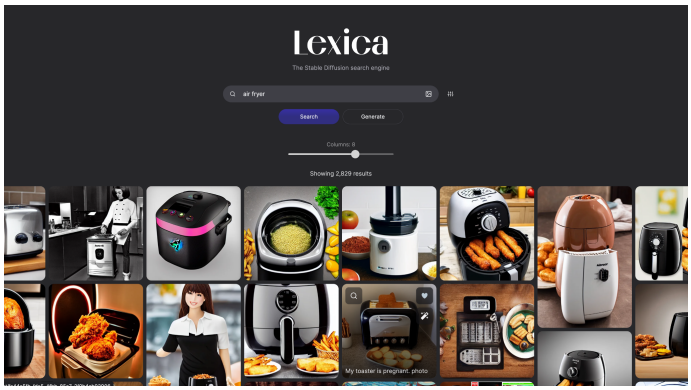


Image 2: Lexica-The Stable Diffusion search engine for reverse engineering[9]

3. Pilot study and early explorations

For the Fall 2022 semester, my collaborator and I conducted pilot studies with eight designers, including interior designers, product designers, and Architects. We also tried using the platform to generate designs for the Interior, Architecture, and Product Design domains (See Image 3). Using the text-to-image for the first time, many participants were surprised at the fidelity of generated outcomes. We found that **uncertainty** is the biggest challenge designers face when using image AI. Specifically, AI generates different outcomes even if the designer enters the same prompt twice. The uncertainty behind diffusion models makes text-to-image a good source for **generating inspiration** while posing challenges for designers to **generate desired images**.

[9] Lexica: https://lexica.art/



Image 3: Comparison between AI-generated outcomes in different domains with prompts on the Dall-E 2 platform (left: interior design, middle: architecture design, right: product design)

3.1. Exploring image AI with sketches as the input

Apart from using text as the input, are there other ways to secure better design results? Some designers are visual thinkers, and they may lack the skills for prompt engineering. How could we bypass this contour while securing more desired image outcomes? Recent research proved using an initial image (image prompt) can improve subject representation for generative art (Qiao et al., 2022). ControlNet (Zhang & Agrawala, 2023) also demonstrates that adding more control-like contour lines could greatly improve the certainty of image outcome for the composition.

Using the DreamStudio platform, I found using design sketches as the input can greatly reduce the uncertainty of the results. Using the left design sketch as the input, I rendered the high-fidelity outcome within seconds (see Image 4). This makes me interested in exploring design sketch-AI generation collaborative workflow.

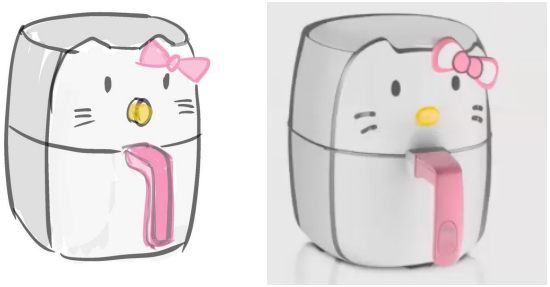


Image 4: Left: design sketch input,
Right: high-fidelity product image output by DreamStudio

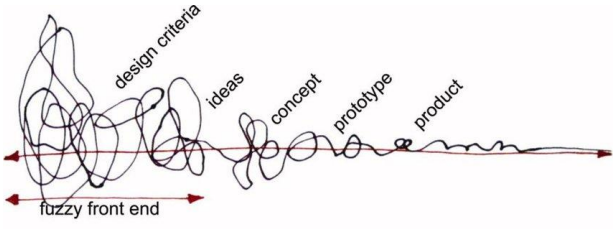
3.2. Image AI-supported design communication

Design communication is hard, and researchers are debating why agreeing on a design solution can be troublesome (Jenson et al., 2006). Researchers have conducted a literature review for

Architecture-related design communication (Norouzi et al., 2015b). Architecture-related design communication involves different stakeholders, and ambiguity hinders communication processes (Norouzi et al., 2015a). Many ways can hinder communication, like the designer does not take full account of the client's idea, a lack of communication, etc. Researchers are developing communication technologies to facilitate design communication (Dekker et al., 2014). We need a structured organization to facilitate design communication (Chiu, 2002).

Harnessing the fast representation and high-fidelity characteristics of image AI, I found it valuable, especially in the early stage "fuzzy front end" (see Image 5), when both the designer and the client lack visual materials for discussion, but it important for the design outcome (Sanders & Stappers, 2008).

Can image AI be a resource for supporting design communication? What would image AI-mediated design communication look like? For the most-common design communication process, it could take a lot of back-and-forth communication processes.



Img 5. The front end of the design process
source: Sanders & Stappers, 2008

3.3. The relationship between the two studies

My end goal of the thesis is to channel the competence of generative image AI to the design community. Two studies target answering different questions. Study 1 targets individual creative practitioners, while Study 2 targets design communication. I found image AI can support both of these two important processes, so I conducted two separate studies. Based on the study findings, my future work will be: Firstly, building design tools utilizing image AI using design sketch as the input. Secondly, building a design communication platform utilizing image AI. While they are under the same larger scope, they target different aspects of design practice.

4. Study 1: Exploring design sketch-image AI collaborative workflow

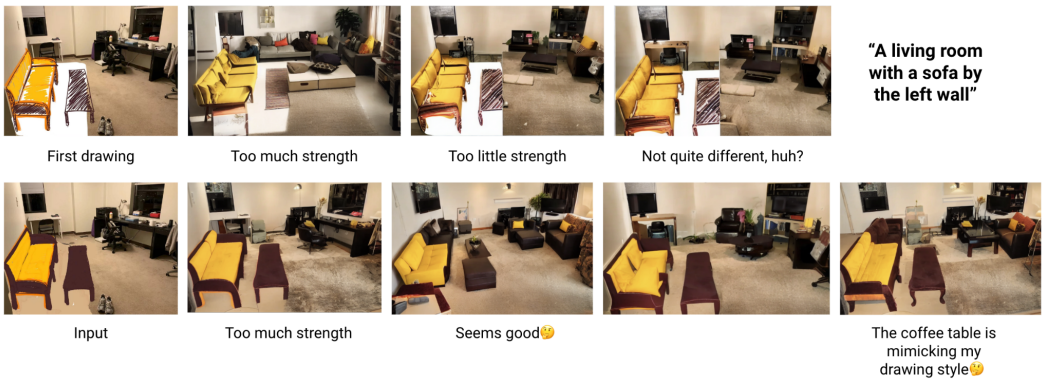
4.1. Research Context

Drawing in compensation with text input reduces the uncertainty of generative image AI results and renders desired design results. I tried the image input of my bedroom and used the diffusion model to render those designs. I experimented with image-only input (see Image 6) and image with sketching

overlay as the input (see Image 7). Using rough design sketches and adding more constraints could "guide" image AI's results better toward the direction I want.



Image 6: Experimenting design using the original image as the input



Img 7: Experimenting design using sketch overlay on the image as the input

4.2. Study Method

4.2.1. Recruitment and Participation

I recruit the participants using posters on the CMU campus, email lists, and word of mouth. In recruitment materials, I provide a QR code linking to the questionnaire (see Appendix A) for recruiting participants. Participants fill in the questionnaire about their design training experience and express their willingness to participate in one or more studies. After screening the participants with the criteria: 1. Be proficient in English 2. Having more than three years of design study experience 3. In the Architecture or closely related domains (like Urban Design, Computational Design). Finally, email the participants and

invite them to study. Each study lasts 80 minutes, consisting of a 10 minutes introduction section, 45 minutes design section, and 20 minutes interview section.

4.2.2. Study Organization and Activities

Introduction Section
In the introduction section, I go through the introduction document with the participant, then let the participant use an iPad to sketch a **mug**, upload it to the platform for making variations and then download it back to the iPad for making drawing overlays. The 10-minute introduction section aims to get participants familiar with the AI tool.

Design Section
Then I proceed to the design section. They are assigned the same design task:

> ***You are an Architect, and your client is a famous hotel brand. They need to build a new hotel near the sea. Think about your favorite architectural styles and design this hotel.***

The participants can use any software/search engines needed, but we encourage them to practice this collaborative workflow. They will use the DreamStudio platform for variations/renderings. The participant keeps this iterative process until they are satisfied with the design, wish to stop, or reaches the time limit of 45 min.

Interview Section
Finally, I proceed to the semi-structured interview section with interview questions listed in the Appendix. I record the study section, use Otter.ai for transcripts, then use google sheets for qualitative encoding by highlighting the **key points** related to the research question and using **memos** to denote interesting insights.

4.2.3. Participants' demographic information

Table 1. Participants demographic information sheet

ID	Gender	Age	Design student/ Professional	Major/ job title
S2D1	F	24	Design student/Masters	Computational Design
S2D2	F	prefer not to answer	Design student	Architecture
S2D3	F	25	Design student/Masters	Architecture
S2D4	M	28	Professional designer	Advanced Architectural Design
S2D5	M	25	Design student/Masters	Computational Design
S3D6	M	24	Design student/Masters	Computational Design
S2D7	M	26	Design student/Masters	Computational Design

S2D8	M	32	Design student/Masters	Computational Design
S2D9	M	33	Design student/Ph.D.	Computational Design
S2D10	F	34	Design student/Masters	Computational Design
S2D11	F	24	Design student/Masters	Urban design

Table 2: Designer-participants design sketch and image AI experience

ID	Design Study Exp. Years	Design Work Exp. Years	Design sketch tools	Design sketch frequency	Experience in design sketch	Frequency using generative image AI	Hours spent on generative image AI	Ever used image as image AI's input
D1	6	2	Drawing on the paper	On a monthly basis	A little	I used it a few times	1-5 hours	Yes
D2	7	5	Drawing on the paper	Several times a month	A lot	I never used it before	0-1 hour	No
D3	6	2	Drawing on the paper, iPad	On a monthly basis	Some	I used it a few times	5-10 hours	Yes
D4	6	5	Drawing on the paper	On a daily basis	A lot	I use it on a weekly basis	10-30 hours	Yes
D5	6	3	Drawing on the paper, iPad	Several times a week	Some	I use it on a monthly basis	5-10 hours	Yes
D6	6	0	Drawing on the paper, Hand-painted board, iPad	Several times a month	A lot	I never used it before	1-5 hours	No
D7	5	1.5	Hand-painted board	Several times a month	Some	I used it a few times	1-5 hours	No
D8	6.5	9	Drawing on the paper, iPad, CAD	Several times a week	Professional	I used it a few times	1-5 hours	No
D9	11	3	Drawing on the paper	On a daily basis	Professional	I used it a few times	0-1 hour	Yes
D10	6	8	Drawing on the paper	I seldom sketch	Some	I used it a few times	0-1 hour	No
D11	7	1	Drawing on the paper, iPad	Several times a week	Some	I never used it before	0-1 hour	No

I conducted studies with 11 Architecture students who has at least 5 years of Architecture-related training. All participants are architecture students studying Architecture-related domains like Architecture, Computational Design, Urban Design, and Advanced Architectural Design. Years of study in Architecture-related domains ranging from 5 to 9 while the work experience in years ranges from 0 to 9.

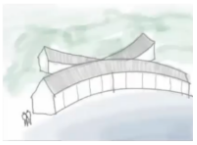
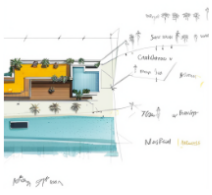
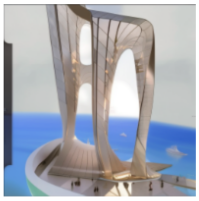
The first three designers (D1-3) had difficulty using DreamStudio to make variations with the iPad sketch input. From the first three sessions, I found prompt engineering and parameters adjustment is a technique that the designers should be competent at to render design variations with design sketch input. To address the obstacle, I added hints to get the most out of these outcomes in the introduction document, highlighting “professional architecture rendering” for generating the best outcomes. I also provide guidance when they need help or get stuck in the design process, like encouraging them with varied prompts and adjusting other parameters (like adjusting the strength of the image).

4.3. Study Findings

Table 2: The final design, design duration, and correlating prompt

*P2 used the image generated directly from the prompt without the image input

*P9 used the original sketch as the final design, as P9 is not satisfied with any image AI generated

ID	Final Design	Design Duration Min.	Correlating Prompt	ID	Final Design	Design Duration Min.	Correlating Prompt
P1		54	"Building perspective of tropical beachside hotel, timber structure, curve roofline"	P7		50	"future, brave new world, 1984, cybernetics, professional architecture rendering"
P2		36	"red building with a sea background and lots of trees with frank lloyd wright style" (*Did not generate from image)	P8		53	"a large hotel with green roofs on the beach overlooking the ocean. With the addition of a large patio on the beach with giant "HILTON" letters in the style of the famous "AMSTERDAM" letters
P3		48	"beach hotel in architecture 3k render style"	P9		74	*Original Sketch
P4		58	"Realistic sunset view, realistic style, famous luxury hotel on the beach of florida, parametric curvatures in architectural design, organic in form, add people on the beach, 4k"	P10		50	"Watercolor image of building with colorful glass"
P5		45	"A sketch of a luxurious hotel, an architectural rendering image. Floating in the ocean with 2 yachts, and a helicopter on the sky around to transfer people"	P11		43	"a master plan/roof plan of the beachfront hotel design proposal. the hotel has 3 stories, with yellow brick roof and white exterior. on the the second floor, there's a terrace with a swimming pool. in the middle, the brown platform is the entrance and can be also used for outdoor performance stage as well as outdoor cinema activities. the hotel also provide a private beach for their customers, where there's a deck/pier extended to the sea, and water sports zone for fun."
P6		49	"a building in zaha hadid's architectural design style by the sea"				

4.3.1. How designers work with image AI

Design sketch compensates for what designers can't achieve with text input. When AI is "stupid" and fails to render some parts of the prompt, the designer returns to iPad drawing to overcome the challenge by drawing the overlay. Designers find sketching the input could produce better results that suit their true intentions. For instance, P6 sketched some structure overlay on the left bottom image, and AI started to "recognize" the structure P6 wished to express. P6 drew blue on the right bottom image as the overlay, and AI started to render the ocean in the image (see Image8). It's like maneuvering an autonomous vehicle. When the vehicle is off the road, the designer takes control of the steering wheel and guides it back to the desired lane. In the pilot studies, we only allowed designers to use text-based generation. One designer asked if they could use an iPad to draw some overlay. We see this repetitive pattern across many participants (P4, P6, P8).

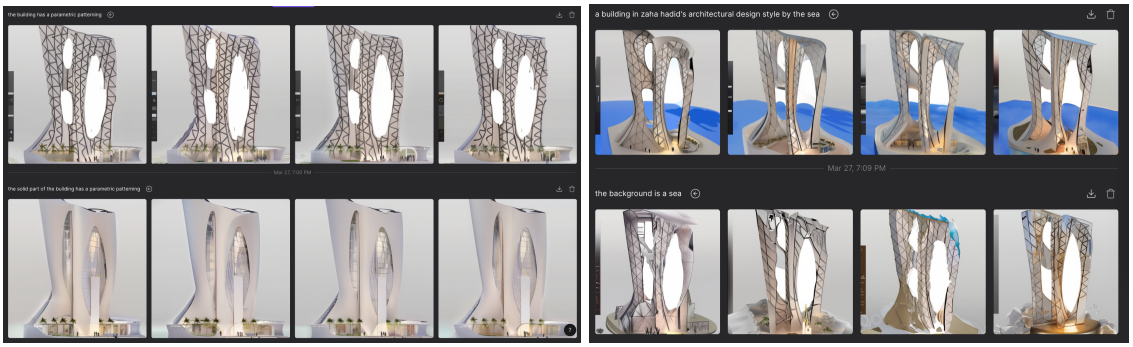


Image 8: Screenshot of the platform P6 works on

> *"This one, and I asked her to change it to sunset, you know, kept getting the same kind of atmosphere as this one. So I had to **go back to the drawing pad** as much as possible." — S2P4*

> *"So, I just go ahead and go to the Procreates and try to like **manually just add the structure,** and hopefully they can just render it to be something like a structure."*
> *—S2P6*

> *"So what I did is I just went back and then **drew some blue color myself** on the Procreate" — S2P6*

Designers steer to the direction and keep selecting the good design results. While the designer sometimes relies on AI to design, designers still play an active role in adjusting the parameters and prompts according to the results, and they take charge of the whole process. It's not like driving a full automation vehicle, but they are still sitting behind the steering wheel. Getting variations based on the images is like a tree structure, and the designer has to decide which branch to go to and when to stop on a certain branch. Sometimes the designer has to step back and go to another branch. If they keep letting

AI generate based on one direction, AI will go to the very end of the branch, and the image will look chaotic (see Image 9).

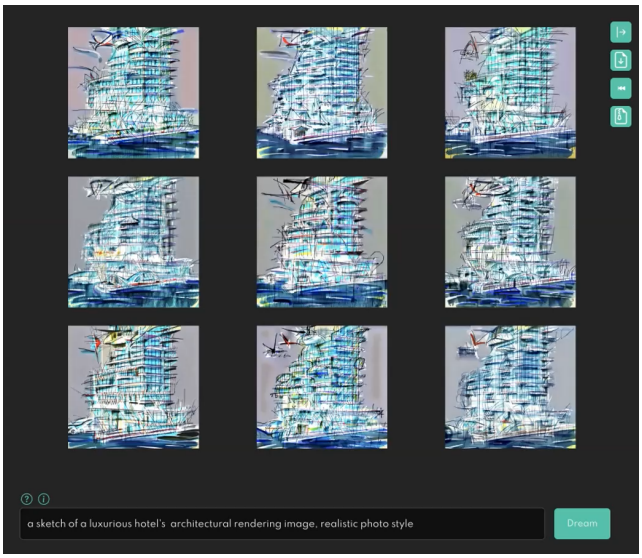


Image 9: Screenshot of images P5 generated with image AI

> *"It's kind of like a **tree structure** where you might know this might be the right thing that you want to go. But if you want to go further in my direction, you have to **go back** and then go the other direction to **go to the right branch**." — P5*

Design ideas drift while in collaboration with AI. The designer is not satisfied with some results at the very beginning, but later on, they find some results do give them inspiration even if it's what not they initially intended. For instance, P5 found an AI-generated hotel on a huge boat (which seems like a cruise ship); they said, "If they had enough money, it's achievable."

> *"Sometimes I might be **persuaded** by it. If I have, like, if my client have enough budget, am I just, like, build it in Rhino or something, render it and then give it to them " — S2P5*

Designers change the drawing behavior to better collaborate with AI. P11 found that AI did not recognize the roof that well, so she changed the drawing color on purpose to another color to facilitate AI.

> *"So I just **changed** the **roof color to try it again.** And the output looks more kind of close to my expectation." —P11*

4.3.2. Benefits and challenges working with image AI

AI help generate inspiration and develop concepts. Among all the designers, most of them find AI tools as a good source for **design inspiration** search for the early-stage design processes. Almost all participants appreciate AI as a good way of **searching for inspiration** and giving **variations** for the

early-stage design. However, P4 mentioned that images are too conventional-looking (see Image 10) while they aim for a more creative shape.

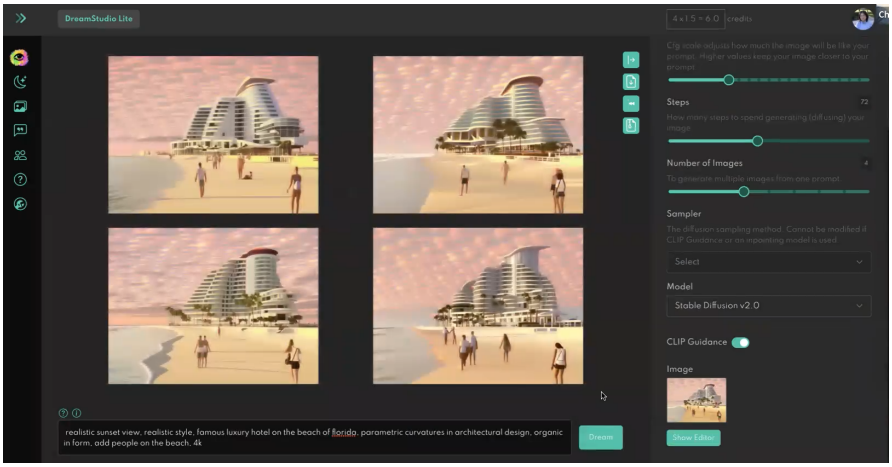


Image 10: The platform P4 worked on with the image generated

> *"And **expands the possibilities** in a very clear way… you can see the ideas **keep evolving**." — P5*

> *"I think it works really well in providing you with some **different possibilities**. So it's, I think it's a really great **brainstorming** and, and the like **concept development** tool." — P6*

> *"But it still feels too close to the **convention**, in terms of aesthetics and ideas." — P4*

AI enhances the design sketch and helps with repetitive work. Many participants(P3, P5, P8) mention that AI helps them enhance the design sketch and improve the image quality, including transitioning from low-fidelity to high-fidelity, mapping the sketch drawing to a more **realistic picture,** and uniforming the style of an image. Moreover, they mentioned AI help them **with unwanted mundane work.** For instance, AI post-processed the image with the designer's sketch overlay, and they get the final image that aligns all the styles within seconds (see Image 11). For instance, P5 mentioned a project he did designing the interior of a high-end hotel. It requires a lot of **repetitive work,** from design sketching to **3d modeling and rendering**. It would be helpful to incorporate AI tools into that process to get a fast rendering.

> *"If you give a basic render, and then you just type in some commands, it **improves the quality of the image** a lot more, which I've seen quite a bit of people doing. " —P3*

> *"There's a time that we're, like, assigned to design the whole interior of a shopping mall in Hong Kong. … But there's just a process that is kept like **sketching** the ideas and making the ideas into a **photorealistic image** that does something very, like **takes too much time**. … So I think if AI can kind of fit into that pipeline…" —P5*

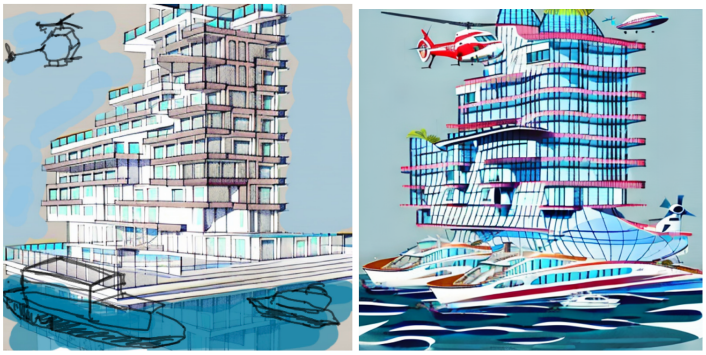


Image 11: P5's input (left) and AI's output (right)

> *"And I look at it and I go yeah, this is actually something that **enhances the sketch**. So I was surprised.. .I think that's a **desirable sketch quality** that I never really even asked for." —P8*

Designers lack proper prompting skills in communicating with AI. Designers had a hard time communicating with AI at the very beginning. There exist some learning costs for designers to utilize the diffusion model fully. The designers use **"conversation"** with AI instead of using **descriptive words** for the Diffusion Model to process them into the image. For instance, by entering "I want to make the mug have an illustration of a yellow cat on it" with an image, P6 failed to get the output image that aligns with their command (see Image 12). Although we provided the prompt guide in the introduction document, many designers are still inclined to use conversational communication.

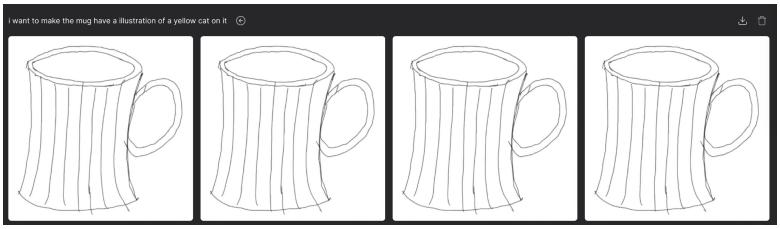


Image 12: Identical images generated by P6

> *"There is some sort of **gap** where I don't know how to create the right image that I want" —P3*

> *"Yeah, well, the challenge I have is, I know that the AI model is not really **thinking the way that we comprehend things**." —P6*

Image generation is still a black box for designers. Although designers mentioned using an image as the input works better than using a design sketch, they still use brute force trials adjusting the parameters when they are new to image AI. P1-3 encountered the same challenge that the AI is not giving enough variations based on their image input. For instance, P1 keeps getting identical results from the platform (see Image 13). It appears to be a black box for the designer to understand whether it's their misoperation (like not setting the proper parameters) or the AI's fault, like system shutdown. It's unpredictable for them to interpret what's next for the results. P6 also keeps getting identical images from the very beginning before getting variations (see Image 14) .

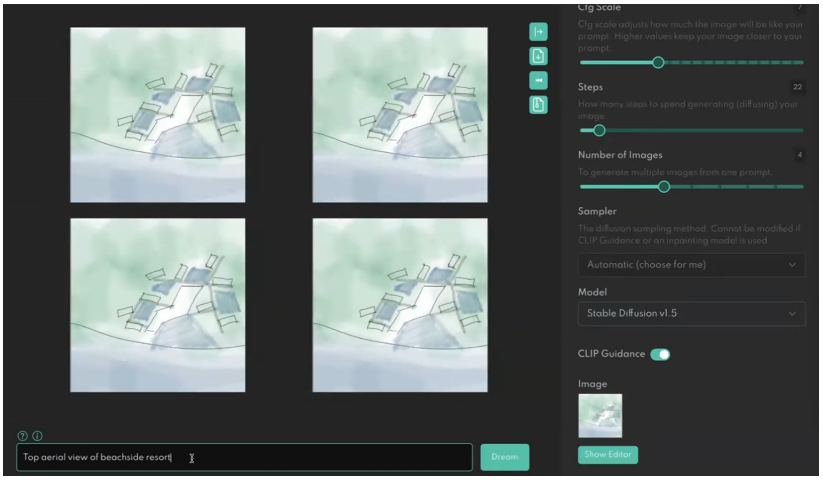


Image 13: The screenshot of P1's generated images



Image 14: Part of the images P6 generated during the session

*"And when I **adjust the steps** it takes, before it generates, before it outputs, they're still identical. So I was **quite confused** as to why this happened." —P1*

*"It was just giving **the same drawing** back to me. So maybe it's the way I do it? I'm not sure why that didn't work quite well." – P2*

*"I think the biggest difficulty was **getting something like another image**. It showed me the same thing again and again, which I was kind of confused by." —P3*

*"I think generally **drawing, as an input,** seems to be **perceived better than text prompt**." – P4*

"I'm not sure what these parameters actually work. So I want to know about that." —P8

AI could not understand the Architecture domain term. 3 designers mentioned that AI tools could not understand Architecture terms specified in the prompts. P6 specified in the prompt that he needs that building "**with tectonics facade**," which is easy for the Architect apprentice to understand, but he failed to get the expected images. P4 wanted a more organic shape for the building, but AI could not understand what organic in Architecture means.

> *"when I pass on like an **organic** kind of a word to the text. A designer will know what that means in terms of form that has a **biometric** or **biomimicry** term to it, but the computer does not know…" —P4*

> *"I want the this tool to be able to identify what I mean by what is the **facade** of the building" —P6*

AI generates surreal images that are not suitable for Architectural purposes. Generating unrealistic images hinders the design processes. P1 and P6 both mentioned that they are getting images that are **not feasible for the purpose** in the real world. P1 is getting a building that has tiles on the floor, while P5 is getting images of the building on the sea (see Image 15), which is not suitable for common architectural construction.

> *"... when I was looking at those images, I said, Oh, **this is really not realistic**. Because there's something that looks like a roof structure or a roofing material that's actually laying on the ground." —P1*

> *"But some of the images like this one might **not make sense** at all." — P5*



Image 15: Left: the image generated by P1 image with the tiles on the floor
Right: the image generated by P5 with a hotel on the sea

The tradeoff between designer's flexibility and perceived utility. There is a tradeoff between the designer's flexibility and the perceived usefulness of AI. P5 and P6 just input rough design line sketches; they were quite surprised by what the model generated. They are open to those directions AI provides. P9 has a more clear image of the design in mind and just wants to use AI to turn the design sketch into

Architectural rendering. P9 is not satisfied, as AI did not translate the right style ("Renzo Piano style") described in words clearly to the output (see Image 16).

> *"I feel like producing a really **quick, messy idea**, again, just to convey, like, the very **loose intent and emotion** of a potential project. I think it did that well. " — P8*

> *"...Because I have a photograph in my brain, I have a **photograph**. I have a photograph in my brain. I know what it is. " —P9 (P9 describes the gap between the images generated by AI)*

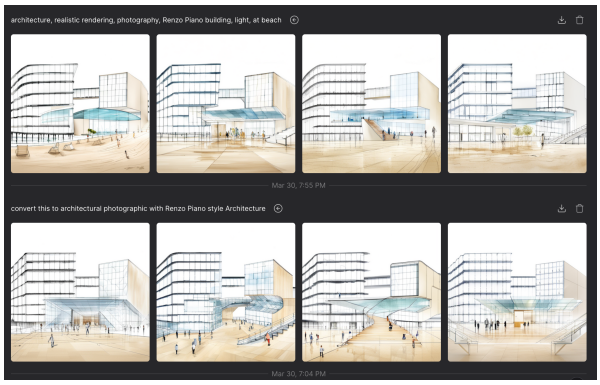


Image 16: Screenshot of images generated by P9

4.3.3. Guidance for future image AI tools building

An integrated platform for direct drawing and rendering. An integrated platform is desired for the designer to draw and hit the generation button to get the AI-processed image fast. Participants mentioned they don't want to go back and force from the iPad to the computer for the processes.

> *"I feel like if there was more of an **integrated approach** to like drawing, actually just drawing on the interface …. go back and forth between the two platforms and stuff like that." — P8*

> *"**I don't want to come back to the drawing pad** to do the file transfer processes." — P4*

Designers wish to have more detailed controls with AI. Although image input does reduce the uncertainty of image AI, many participants are still seeking more detailed control. Midjourney already has that feature for setting detailed strength of each word that P5 desires. The partial generation P8 mentioned also exists in Dall-E 2 as an in-painting and out-painting feature. A designer with both Machine Learning and Architecture design background pointed out that model fine-tuning would be desirable. They also wish to have their own model preset saved for future Architectural design practice.

> *"For example, in Google search, if you really want to, quote, like photorealistic realistic style, and kind of refine it to get a **priority**. It seems like for this, it's really hard to **prioritize the descriptions**, or like, or the filters on here." —P5*

*" ... like obtains total control over the drawing, like every output is a brand new instance of the entire image, I'm looking forward to a little bit **more control** over like **partial generation**" — P8*

*"I can **fine-tune** this stable diffusion model. And then I can convert a data image into that tone, you know, we need to **fine-tune** it if you want to use a specific domain." —P9*

Domain-specific generative image AI tool that understands the domain term. More than three participants (P4, P6, P9) mentioned wanting to have Architecture-specific AI that can understand the Architecture terms. P4 mentioned that it would be great if they could choose different Architectural styles and generate images with those styles.

*"... Richard Rogers or Renzo Piano, those are the people who are very interested in exposing **the structure, exposing tectonics**. And I don't think, like, when all the tool has the ability to identify what was like, I mean, by tectonics, what's the **structure** of those things, but, but if like, they're able to detect those, I think it's gonna make it very interesting." —P6*

*"For example, you have a **library of each style** and a certain style of **architecture**, labeled by their names of architects." —P4*

4.3.4. Willingness to incorporate the AI tool into the current workflow

Most participants are willing to incorporate the AI tool. The first three participants did not express their will due to the obstacles they encountered, and AI failed to give enough variations. However, they say that they wish to see AI give variations. For participants who did not have image variation issues (P4-11), nearly all expressed willingness to use AI in the future workflow.

*"Because we're kind of **exploring the design**. So if we had many options generated in the beginning, we can get to a **better option**." —P2*

*"I think it was **pretty efficient** at capturing the form **in the first few iterations**. And that's desirable, I think. " —P4*

*"I certainly think it would **enhance the design process**" —P8*

Designers are willing to use AI for early-stage design rather than finalizing design. Participants acknowledge AI's role in helping early-stage **design exploration and brainstorming** (P6, P10), they also think it's hard for AI tools to behave in the latter design phase when they have a clear design idea and only need to finalize their design decision (P4, P5, P10). Some Architects, especially Architects with many years of experience, would not use the images directly shown to the clients. Firstly, they think what AI generates is not the final design (P4). Moreover, our participants believe it may **influence professionalism,** and they don't want the clients to know that the images are generated by AI (D11).

*"Like, I have access to this, I would definitely use it to **brainstorm some preliminary ideas**." – P6*

*"Oh, in a way that I said before, like, **making inspiration**, not making the **final images** or final decisions." —P10*

*"But it's **not critically helpful** in terms of helping you **finalize** the design" — P4*

*"When the design goes later, and later it requires much more **precision**. And it might be **very hard** for this kind of image-driven AI to behave." —P5*

Designers believe AI helps them be more creative. Designers (P6, P8) think with image AI, they can be more creative in the design processes. We see that AI could act as a creativity support tool in future practice.

*"it definitely will encourage me to **be more creative** about the exterior design" – P6*

*"It would enhance the ability to **explore initial ideas** more... it's not so much enhancing the sketching process so much as it's enhancing the **inspiration process**." —P8*

4.4. Study Discussion

Most participants are willing to incorporate this workflow in their future practice. They favor AI the most in providing design inspiration and helping to brainstorm at the very beginning stage. They state that AI is great at generating varied designs, even with little input. Participants appreciate AI can help them explore many design directions even if they give AI very little. However, they also mention it's hard for AI to act in the latter stage of design when they have a clear "design in mind". However, new skills like prompt engineering and parameter adjusting are new skills they need to learn or practice to use AI effectively, or even let AI make desired variations at the very beginning. Working with image AI, designers still need to actively select which branch to go to when AI provides design solutions and actively select the desired design results.

Limitations

All participants, no matter whether they have Architecture related work experience or not, are all current students. It poses a limitation to generalize the finding to Architecture practitioners. Among all the participants, 7 are in the computational design domain, so they already have some exposure to computational approaches to assist design. Thus, they might be more willing to incorporate the new technology into traditional Architectural practice, which may positively influence their willingness to use AI and their proficiency in generative image AI. Moreover, a 45-minute section for the study is limited, and some of them may not have enough time to develop proficiency in using these tools with our

guidance. Our study participants represent designer who has less than hours of experience in using generative image AI, this would also influence the design results.

5. Study 2: Exploring image AI for supporting remote synchronous design communication

5.1. Research Context

In this study, I explore how AI tools could support the early-stage design ideation processes with the clients involved. Inspired by the need-finding machine (Martelaro, n.d.) that enables in-situ design research with the machine that's locational with the user, and the designer can use the machine to conduct remote design research, I wish to study the image AI-supported design conversation in which the client could even "show" what they want directly (see Image 17). Visual material is important for conveying design directions, but at the very beginning stage of the design process, both clients and designers lack those materials. For product design, the designer uses the following "social things"-mood board and sketch for design communication (Lucero, 2012):

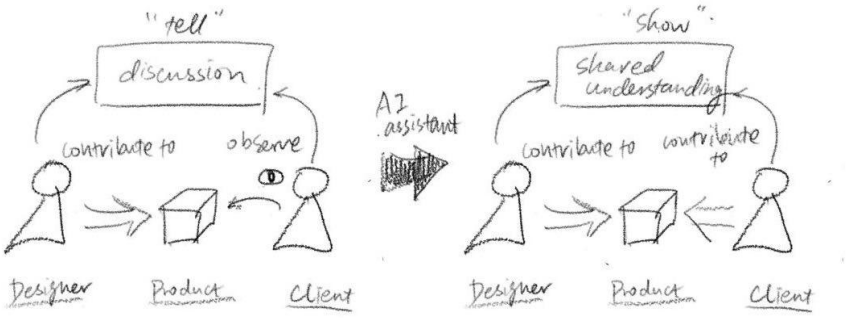


Image 17: Transition from tell to show

Mood board
Mood board consists of "visually stimulating images and related materials" (Lucero, 2012), it serves as an essential way to convey the design style and ideas in the early design stages can improve communication during a design process (Mcdonagh & Storer, 2004).

Sketch
A sketch is a powerful tool for early-stage design communication before the 3d model construction and renderings. Sketching is an easy way for designers to ideate with ideas and convey more form-based design directions to clients. Sometimes designers also sketch **with** clients to discuss the possible design direction. However, due to the abstractness of Architectural sketches, people perceive the same sketch differently. They are all from the Architectural domain and have different years of training (Menezes & Lawson, 2006).

Thus, a more solid and concrete way to bridge the design communication is desired in the processes. I start exploring if image AI can help in this complicated process, given the fidelity it gives.

5.2. Study Method

5.2.1. Recruitment and Participation

I recruit the designer participants by using posters on the CMU campus, email lists, and word of mouth. In recruitment materials, I provide a QR code linking to the questionnaire (see Appendix A) for recruiting participants. Participants fill in the questionnaire about their design training experience and express their willingness to participate in one or more studies. After screening the designer participants with the criteria: 1. Be proficient in English 2. Having more than three years of design study experience 3. In the Architecture or closely related domains (like Urban Design, Computational Design). I recruit client participants with posters on the CMU campus, and email lists but mostly word of mouth. The inclusion criteria are: they are not in the Architecture-related domain now and are willing to participate in this study. Then I contact the participants and invite them to study. Each study lasts 80 minutes, consisting of a 10 minutes introduction section, 45 minutes design section, and 20 minutes interview section. Most of the client participants I recruited are not in Pittsburgh.

I pair one designer-participant (someone who has a design background and is the designer for this design project) and one client-participant (someone who has no design background and acts as the client for a design project which the designer-participant designs for) for one session. The inclusion criteria for the designer-participant is that they should have more than three years of Architecture-related experience in that domain. The inclusion criteria for the client-participant is that they are currently not in the Architecture-related domain and are willing to act as the client for the design project. They use Zoom video conferencing for communication and collaborate on the Figma board during the design section.

5.2.2. Study Organization and Activities

Introduction Section
I first go through the introduction document with the client participant and designer participant, then let the participant use the DreamStudio platform to generate a sofa and upload one **generated sofa image to the Figma board along with the prompt.** The purpose is to get them familiar with the workflow. The 10 minutes introduction section aims to get people familiar with the AI tool.

Design Section
I proceed to the design section. The participants work collaboratively on the figma board on the given design task:

> ***Client-participant asks the designer-participant to design a house by the sea for the client. Please use the design section to achieve this goal together with your client.***

The participants can use any software/search engines needed, but we encouraged them to practice using generative image AI as the main tool. They use the DreamStudio generative image AI platform for variations/renderings. They will communicate on Zoom while using AI tools to generate images individually. They could share the generated images along with the prompt on the Figma board (see Img.

18) with each other. The participants keep this iterative process until the participant is satisfied with the design and wish to stop or reach the time limit of 45 min. A general Figma board after the session looks like this (See image 18).

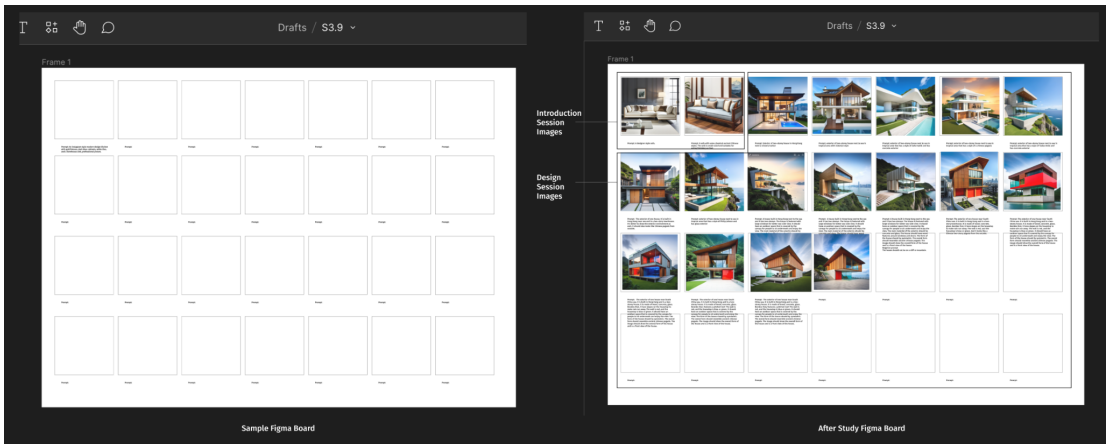


Image 18: Left: The Figma board template for participants to work on
Right: The Figma board after the design session 9

Interview Section

After that, I proceeded to the semi-structured interview section with the designer-participant and client-participant. The interview questions are listed in Appendix B. I used Otter.ai transcript generation and proceeded to Google Sheets for qualitative encoding by highlighting the **key points** that are related to the research question and using the **memo** to denote research insights.

Table 3: Designer-participants demographic information

ID	Gender	Age	Design student/ Professional	Major/ job title
D1	F	24	Design student/Masters	Computational Design
D2	M	28	Design student/Ph.D.	Computational Design
D3	M	27	Design student/Masters	Computational Design
D4	M	33	Design student/Masters	Computational Design
D5	M	25	Design student/Masters	Urban Design
D6	M	25	Design student/Masters	Computational Design
D7	F	25	Design student/Masters	Computational Design
D8	F	25	Design student/Masters	Building Performance
D9	F	28	Design student/Ph.D.	Computational Design
D10	M	25	Design student/Masters	Computational Design
D11	F	24	Professional designer	Architectural Assistant

Table 4: Designer-participants design sketch and image AI experience

ID	Design Study Exp. Years	Design Work Exp. Years	Design sketch tools	Design sketch frequency	Experience in design sketch	Frequency using generative image AI	Hours spent on generative image AI	Ever used image as image AI's input
D1	6	1	Hand-painted board	On a monthly basis	Some	I used it a few times	1-5 hours	No
D2	8-10	1-2	Drawing on the paper	Several times a week	Some	I used it a few times	5-10 hours	Yes
D3	6	3	Drawing on the paper, Hand-painted board, iPad	On a monthly basis	A little	I never used it before	0-1 hour	No
D4	10	3	Drawing on the paper, Hand-painted board, iPad	On a weekly basis	Professional	I used it a few times	5-10 hours	Yes
D5	7	1	Drawing on the paper, iPad	Several times a month	Some	I never used it before	0-1 hour	No
D6	7	1	Drawing on the paper, iPad	Several times a week	Some	I used it a few times	1-5 hours	No
D7	7	2	Drawing on the paper, Hand-painted board, iPad	On a monthly basis	Professional	I used it a few times	1-5 hours	Yes
D8	7	1	Drawing on the paper, iPad	On a monthly basis	Some	I used it a few times	0-1 hour	No
D9	10	2	Drawing on the paper, I seldom do design sketch	Several times a month	A little	I used it a few times	1-5 hours	No
D10	6	3	Drawing on the paper, iPad	Several times a week	Some	I use it on a monthly basis	5-10 hours	Yes
D11	4	2	Rhino	On a daily basis	Professional	I never used it before	0-1 hour	No

Table 5: Client-participants demographic information

*We found C1 had a bachelor's degree in Architecture before the session, while other participants do not have Architecture-related domain experience before.

ID	Gender	Age	Design student/Professional	Major/ job title
C1	F	23	Masters Student	Human-Computer Interaction
C2	M	25	Ph.D. Student	Mechanical Engineering
C3	M	26	Ph.D. Student	Human-Computer Interaction
C4	F	25	Professional	Design
C5	F	25	Professional	Interaction Designer
C6	F	24	Professional	Data scientist
C7	F	30	Ph.D. Student	Learning Sciences
C8	M	24	Ph.D. Student	Computer Science and Engineering
C9	M	24	Ph.D. Student	Computer Science
C10	F	26	Masters Student	Industrial Design
C11	M	24	Masters Student	Digital Media

5.3. Study Findings

5.3.1. Working wells and challenges that participants encountered

Many participants are satisfied with this interaction. Many participants (C3, C6, C10) are satisfied with this novel interaction experience, while some are not (D5, C5, C11, D11). Some mentioned that they are satisfied with the results (D9, C11), but some participants are skeptical (D4) or even not satisfied (D5, C8). More participants are satisfied with the communication than the results. Most of the unsatisfied participants mentioned they were not content with the generated images, but they appreciate having this new way of interaction as it saves a lot of time to reach a basic understanding.

> *"Um, I think AI tools are **pretty helpful right now** ... I really don't know like, what the client wants at the very early stage, he can generate several images to show me so I have like, a simple idea of what he wants, I think this time, this step actually **saves a lot of a lot, a lot of time** of like understanding each other." – D2*

> *"But it's good for the clients to know to use the generator to **gather a basic understanding** of the type they want and then start from there. " – D3*

AI provides visual materials for discussion quickly. Image AI's proficiency in providing visual materials for discussion is favored. It's not good at providing **perfect** results, but the efficiency in providing images that are **close to** their expectation is favored. It does improve communication efficiency and helps to reach a shared rough understanding within an hour. The clients favor it more than designers as it helps realize the idea in mind.

> *"I think AI is really good at, like, giving **fast results**." – C1*
>
> *"I think it works really well, like, when you have no idea or you have a very simple idea. I think it can make your idea or **realize your idea** in a very **fast and efficient** way." –D2*
>
> *" I actually don't really know what I want. I just have a **general sense of preferences** and things I don't like, but I don't really have a very specific building design I have in mind that I can, like, express it. So I would say AI is being a huge part like doing me a favor, kind of, **representing my ideas**, even though I'm giving him so little." – C2*
>
> *"I feel that that greatly increases the process of communication….they increase their **work efficiency** and **communication efficiency**." – D4*
>
> *"In terms of the design part, I think it really **shortens the time**." – D7*
>
> *"I think the most challenge might just be we're talking **remotely**" — C6*

Participants have limited control of the model. Many participants request more detailed control over the model. Using text as the only input is quite limited, and the results are random. It's not AI that's not advanced enough, but the way of interacting with AI is not advanced enough. Participants seek in-painting features and partial generation, but DreamStudio does not support those features.

> *"I think the biggest challenge is that I like the **stability** of this AI. It is a little worrisome, like for one prompt is giving me all kinds of different results. " —C1*
>
> *"can just hoping we get good results and if we if it like doesn't really work out there are very **limited ways** we can say how what's right or what's wrong" –C2*
>
> *" it's not it's not it's not kind of appropriate during a client-designer meeting to do something that you **didn't expect**, and they didn't expect." – D3*
>
> *"Like, I can give you something new **but not totally new so that you can have a back and forth**. But when we are using this software, there's no back and forth. It's totally direct like it's just it. Boom, that's it. All the back and forth is like, I have a new thing, you have a new one, I get a new thing. You have a new one." – D5*
>
> *"I mean, fanciness is only one part of it, it's like the results sometimes differ too much from what I wanted. And there's **no way to really change it** or steer into the way I wanted." – C8*

System bias in generated images. For instance, C9 wanted to generate a "Chinese style" interior but did not get what they wanted as it's not in the pagoda style they specified in the prompt-"It should also looks like a Chinese pagoda from outside." Many participants mentioned the designs are fancy-looking, and the images generated by AI seem like exhibition images (D7) rather than realistic designs (see Image 20). The styles AI can generate is limiting (C1). The limitation in styles is constraining the participants to think more broadly about the possibilities.

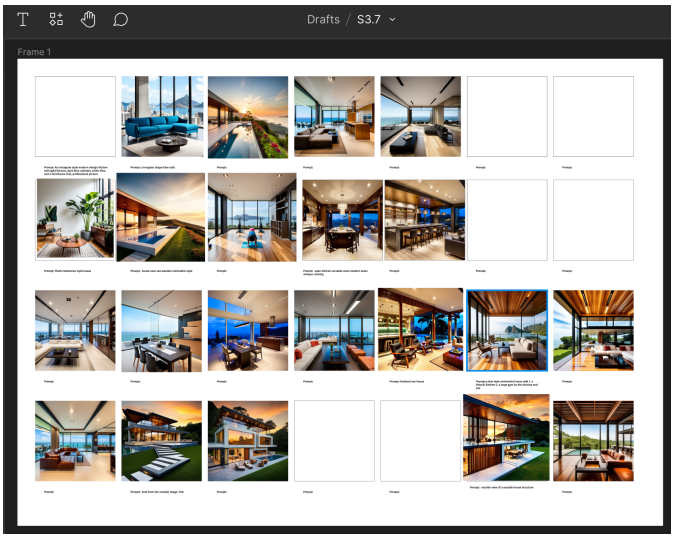


Image 20: Figma board that D7 worked on

> *"Like I would prefer the designer to, like, actually sketch the thing, instead of using some AI tool because the AI tool is very **limiting**, it tends to have these like **very popular images**. " –C1*

> *"So he can choose between these different styles because right now the images I generate from the platform I think only follow **one style, one or two styles**." –D2*

> *"I can pick up some key points to communicate with the designer and told him that which the part I really like, so it's definitely a **visualization communication**. So that's the part I like it so it's more like that AI could help me to get some reference sometimes, but it's **full of the bias** it doesn't provide me various you know, inspiration or reference" –C5*

> *" I sort of feel like many of these images are also generated from, say, a public resource, which probably was from some **propagandas,** and like, you know, **exhibition images**, they are, like, **super fancy** but don't really accurately correspond to a set budget." – D7*

Unsatisfying results for niche design tasks. Once the participant wants more customized design solutions, it's harder for AI to play a role. For instance, C2 specified he wanted a four-floor house, but he failed, because AI always gives house with 2 or 2.5-ish floors. C5 mentioned she wanted to put the table at the corner, but AI keeps getting the more traditional images that put the table at the front of the sofa, but what they really want is a table near the floor. It seems the more niche the design needs, the harder

for AI to generate ideal images. C1 mentioned that maybe for CBD style streamlines Architecture results, image AI is more useful.

> *"But if I'm wanting to design some sort of you know, like CBD type of workspace building then **AI is great because it's very fast** and you don't need a lot of personalization or designed to it any anyway, but like for houses especially like vacation house, it's very niche like yeah, I **still want someone to design for me**" – C1 (C1 suggesting that they wants to use AI for more general and conventional design task)*

> *"The image only has two floors. I don't know why. A lot of times I tried different variations but I still **got two floors**" —D2*

> *"Whatever I change the prompt, it doesn't generate him something I really like. It always puts the table at the, maybe **the center o**f the, you know, the room but I really like to put the table maybe at the right corner or the or the left corner there, so. So that will cause a lot of problems." – C5*

> *"And they are not yet capable of associating all this information together to produce a very, we say, a **close look, design**. " – D7*

5.3.2. Benefits and challenges to communication

Clients use designer's prompts to form better prompts. Sharing the prompt does help the client to form professional language describing what they want. They copy-paste the prompts from the designer and add more details based on that to get customized generations. The clients do use the designer's prompts more than designers do. However, the prompt sharing behavior can be observed on both sides. One participant mentioned that they wished to have a list of the prompts they could use before the beginning of the section.

> *"And then I kind of sometimes like it's a **mutual effort** where we define the final word we want." — D3*

> *"I definitely copy some of my designer's prompts and try to change the keyword to see whether he can achieve what I want. " – C5*

> *"Because, like modernism and postmodernism, and just some of these terms, I won't really know that." – C4*

> *"I don't have a lot of **vocabulary** on how to describe the thing I want." – C7*

Design directions shift too fast in the processes. Changing from one direction to another seems not obvious to the clients but seems like a huge leap for clients. For example, D3 sees the most left and most right images as totally different designs as they are totally different structures, but the client sees them as

similar designs as they both have pitched roofs (See image 21). Shifting from one direction to the other is annoying for designers. Designers mentioned that design is a progressive process, while for generative AI, the high-fidelity design comes out all of a sudden and design plans change quickly with different rounds of generation (D3, D4). It may not be obvious to the client, but in the designer's opinion, those are totally different designs. D3 and D4, who worked as professional designers, mentioned the sudden change is bothersome. Moreover, generated images seem like finished designs, so it's hard for designers to improve further, as designers don't know how they can act based on a design that looks finished already.

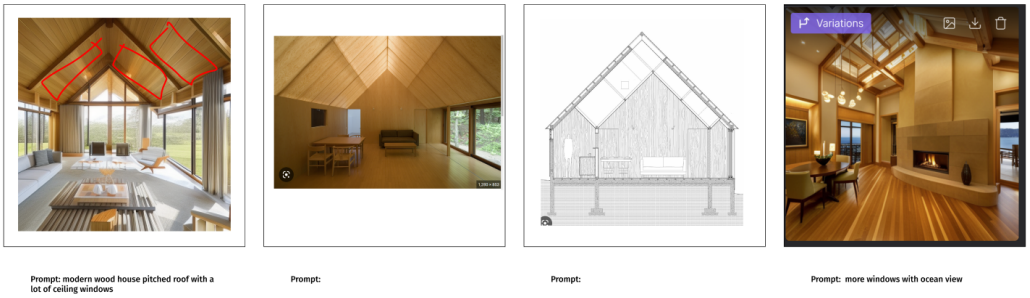


Image 21: Screenshot of the Figma board D3 and C3 collaborated on

> *"So it seems like the image generator can just **change it every second**, it changes so fast and Architects **lose their track of thoughts**. " –D3*

> *"Sometimes like Dall-E, you generate a good image and then how we were saying hey, like that, and everything before that was **discarded**. Like there's no there's no like thought like a **linear thinking process** of I like the shape like the material. " –D3*

> *"The sketch has a lot of potential there that we can develop, develop a lot of possible designs based on the rough sketch. So it's a **progressive process** that you build, I mean, the through progressive process was like, start from nothing." – D4*

> *"I don't know what to do next. I feel like the design was **finished in a second** and the results are totally not as I expected, because it's not my design." – D4*

Participants favor face-to-face communication. Three participants (C6, D7, C7) mentioned the biggest constraint is that they are not talking face-to-face. They wish to show each other the images, but the process is burdensome. It provides insights for us that maybe an integrated platform for face-to-face image generation is one ideal direction.

> *"I think the most challenge might just be we're talking remotely, so it's hard for me like to point that designer this corner is what I don't like and that place need a replacement. So I think if we communicate **in person**, it will be much better. " – C6*

"And that's, like, causing some time delays and, and maybe she'll be interested in one of the other pictures I haven't shown her. So that's really bad. I think this can be solved if it's like, ***in person****. " – D7*

"I think it will be better if it's in person ***face to face****, but Zoom seems to be also okay." – C7*

"So maybe there should be a way for people to collaboratively use prompts or collaboratively share prompts and work on prompt modification together with something like that." – C8

Participants state it might be hard for image AI to assist latter stage design. When it comes to more detailed design needs communication, participants are not that willing to introduce AI into the design session (D4, C6). For instance, D4 mentions that when they get into the details, more factors should be taken into account, like material, cost, etc. They are not sure if AI could help at that stage. For C6, they are more willing to see a designer jumping in and designing the house rather than letting AI designs for them. However, given the time limit, we still need to research further to see if it's because the time given is not enough for them to dive deeper into the design detail or it's if AI's own incompetence in suiting more constraints and giving more customized plan.

"when we ***get into the details*** *of like, what it is and how. Like the material, the cost, all of that, then I'm* ***not sure*** *this would help." —D4*

"I think for the very beginning, I'm happy to use some AI generated image for my house design, ***but later on****, I wish that* ***designer would jump in more*** *and, like, do more of his job, like, on designing my dream house." – C6*

5.3.3. improvement direction for AI tool

Participants seek more precise and flexible control of the outcome. As one major limitation for participants to use image AI is the flexibility of controlling the outcome, more precise becomes one major direction they mention for AI to improve on (C1, C2, D8). The images lack the context of the design, and each time is like a slot machine where the user just "hopes" they can get good results, but many times in vain. It's desired to have some more detailed control like setting the strength to each word, setting some "must-follow" rules for AI to generate images based on (C2), etc. Partial generation based on some good images, like only re-generating part of the image while keeping the rest, is also desired to allow more flexibility in controlling the generation processes (C8).

"So, you can actually play with it or maybe have a ***selection*** *like a* ***drop-down menu*** *to select features or like click on the features of the picture to like and say yes, I want this or yes, no, I want to abandon these. So, then I can have a more precise control over the images. " —C1*

"In reinforcement learning, you have more ***hardcoded or like stronger restrictions****, you may do a better job, but given the accessibility and usability of the top platform and how the time I've spent on this thing, I'd say it is pretty good." – C2*

*“ There are very **limited ways** we can say what's right or what's wrong.” —C2*

*“I guess maybe there's something you could, maybe you could start, like a **mini course** or something just to **educate the client**. Is it like how you can manipulate one rendering and then put in some appropriate prompts for the AI to fill in the gaps? Yeah, I think that's one way of doing it.” —C3*

*“I think maybe generated can only focus like **specific area** we circled on this pictures. So it will not only eliminate the calculation process calculation time, it may cost but also we can keep some components we didn't, we didn't, want to change during that process.” —D8*

5.4. Study Discussion

Communication-wise, given the sessions I conducted, most participants favor image AI for improving communication efficiency and helping bridge the communication gap between the designer and client. Compared with the traditional way of communication, participants favor image AI as a tool to help achieve a shared understanding sooner than the traditional back and force-processes. Image AI-assisted interaction provides a novel way for stakeholders to provide some preliminary design for discussion. My study shed insights about new tooling opportunities for assisting future design communication. Moreover, prompt sharing also helps non-designer in gaining professional terms so they can generate prompts collaboratively instead of letting the designer take the dominant role in the processes. Clients who have had no Architecture-related design training before also appreciate that they can generate some designs and have those images that can represent their ideas for discussion.

Design-wise, participants admit that image AI can be more useful for common Architecture purposes and early-stage design processes. When it comes to more niche, more customized, and rule-based Architecture needs like how many floors designers want to have, participants mention it’s harder for image AI to behave. Moreover, the tendency in generated images (like always output fancy-looking images that may not suit the client’s budget) is hindering the design ideation and communication processes, which the researchers should consider for future design tooling.

Limitations

Firstly, as for the participants involved, the designer participants are all students who are studying Architecture-related majors. Although they all have at least 1 year of working experience, they are not working Architects. 4 out of 11 Client-participants are Ph.D. students, and some are master’s students in different majors. They may not reflect the real clients for an architectural design project. Secondly, as for the time given, a 45-minute design section may be short for them to get familiar with the image AI platform and develop design work to its furthest. Thirdly, I choose a remote communication environment to enable the designer-participant and client-participant both use generative image AI actively, but the remote synchronous communication may not best mimic the real design communication processes.

C1 holds a bachelor's degree in Architecture, so she may be more satisfied with the design she generated herself due to the training she received and the ability to know what she exactly wants.

6. Findings and discussions

6.1. Findings

My work indicates the role image AI can play in the design processes. I studied image AI as a design resource in two scenarios: 1. Image AI in combination with design sketch for early-stage design, and 2. Image AI as a source for bridging the design communication.

For study 1, researching image AI in combination with design sketch for early-stage design, I proposed a new mixed-modality way for designers to work with image AI and test this workflow with 11 Architectural students with at least three years of Architectural training. In the design sketch-AI generation collaborative design processes I observed, designers steer to the right direction and keep selecting the desired design results. The designer's ideas may drift during the session collaborating with image AI, as image AI keeps giving them new design solutions.

For the benefits and challenges, participants favor using design sketches in compensation with image AI for inspiring more design ideations in the early stage of the design process. These 2d images have the potential to inform the following 3d design and design execution (Smith et al., 2023). They also favor that AI enhances the design sketch and helps with repetitive work. However, the "black box" phenomenon in image generation remains, even if we add one more modality (sketch image) as the input, and designers new to image AI has to gain the proper prompt engineering and parameter adjustments skills to work with image AI efficiently. Moreover, in the latter part of the design, when designers have a clearer picture of what design to achieve, participants say it's harder for AI to act. AI may not understand Architecture domain terms, which is an obstacle for Architects to use image AI efficiently.

For the real-scenario usage, most participants expressed their willingness to incorporate image AI into their future work. Still, they are more willing to use image AI for early-stage design rather than finalizing design. Participants state that image AI enables them to be more creative in envisioning the design solution.

Study 1 also provides directions for image AI tools to improve on and potential ways to extend the work for developing design-support software (Amershi et al., n.d.). Apart from advancing prompt engineering skills (Liu & Chilton, 2022), study 1 proposes and experiments with a novel way for designers to navigate image AI using design sketches in design scenarios (Qiao et al., 2022) and suggests possible design tooling opportunities based on generative image AI. For example, integrated software on the drawing device like iPad using the design sketch and text prompt as the input; a platform that includes more features to allow more detailed control, like in-painting and out-painting, etc. Finally, as designers seek a domain-specific image AI platform that can understand the domain terms and knowledge, a domain-specific generative image AI platform may be a future tooling opportunity.

For study 2, researching image AI as a source for bridging the design communication, many participants were satisfied with this novel way of interaction. Designer participants and client participants favor image AI's role in providing visual materials quickly, which enables more solid conversation between them in a short time. This helps bridge the communication gap.

For the benefits and challenges, some participants mentioned that AI facilitates more efficient design communication and shortens the time to reach a shared understanding compared with traditional approaches. However, like study 1, participants state they are seeking more detailed control over image AI's output: including partial regeneration and more Architecture-oriented style selection, which DreamStudio does not have. Participants mentioned that the image AI always gives fancy-looking images: images generated by AI are close to fancy advertisement-style images. This hinders their design processes, and those images are not suitable for their design goal and preference. Finally, participants state it is hard for AI to provide more customized design solutions. For example, participants have some set rules and hard-coded design goals: like, how many floors they want the building to have, where they want to put the furniture in the house, etc. For real-scenario usage, they are more willing to introduce image AI into the early stage of design rather than later stage design, when they need more customized and detailed design solutions.

As for the communication part, prompt sharing reinforced by the template we provide in Figma enables client participants to use the designer's prompts and language to describe the design they want, even if they did not have Architecture-related training before. Sometimes designers also use the client's prompt or turn the client's description of what they want into a prompt to generate Architecture designs. The prompt-sharing behavior observed provides insights into how we can design a system for collaborative prompt engineering to achieve a shared design goal.

Study 2 provides insights about whether image AI can or can not serve as a tool to bridge design communication. The benefits and challenges witnessed in the design communication mediated by generative image AI can inform future collaborative image AI platform building.

6.2. Discussion

For the research limitation, nearly all the designer participants in the two studies, except D11 in Study 2 (who is a working Architect), are all Architecture students who are not in practice, although most of them had Architecture work experience before. Most of them are new to image AI, so our research may only reflect the Architects who do not have much experience working with image AI. Moreover, the 45-minute design section in the two studies is short for them to develop familiarity working with DreamStudio, this specific generative image AI platform. Given the time limit, they may not be able to push their design work to the furthest. The design specifications we gave in the two studies are also broad, while in real design projects, Architects usually receive very specific design specifications. Further studies need to be conducted with professional Architects to see the implication in a real working scenario.

7. Conclusions and future work

7.1. Conclusions

With the 80-minute experiments conducted on mostly Architectural students, Study 1 portrayed image AI in combination with design sketch for design workflow, and provided insights for guiding the future sketch-based system design. Within the 45-minute design section period, our study suggests that image AI in combination with design sketches could help render quick design ideas, and help designers be more creative. Designers are willing to incorporate image AI into future practice, especially early-stage design. Study 2 characterized generative image AI tools' affordance in remote design communication between clients and designers. It indicates that image AI has the potential to be utilized for bridging the communication gap quickly. In both studies, our preliminary experiments suggest that for novice image AI users, image AI might only be good for the early stage of design brainstorming or ideation stage. Both studies' participants mention it's hard for image AI to facilitate the latter part of the design when they have a clear idea, or need a more customized design solution with specific and detailed design goals. The bias in the generated image is also worth noticing as a constraint for image AI to support creativity.

Given the study domain that we focus on-Architecture design and the different natures of 2D and 3D design, I encourage researchers to look at broader implications of image AI for other design domains like graphic design, interior design, product design, and UI/UX design. Like Gmeiner's study, a longer study period is needed to see whether designers with more experience working with image AI, and without the time limit, will gain the skills to better incorporate image AI as an effective design tool (Gmeiner et al., 2023).

For future design tooling opportunities, my study indicates that image AI has the potential to assist both design ideation and design communication. In both studies, participants sought more detailed control over image AI's outcome. Though more versatile design tools exist, like Midjourney that supports setting the prompt strength to each word, we focus on DreamStudio favoring its simple control panel and its convenience (as it's web-based). I would also encourage research into other more professional platforms that allows more detailed control to see if they can act as better design tools. If not, I would encourage more versatile image AI design tool design and development. At the same time, providing related educational materials (like the prompt-engineering guide, and prompt adjustment guide) is needed for designers to harness image AI's potential and use image AI as a helpful design tool.

Zooming out to look at broader AI-supported design systems, I contend it is not that the AI-like diffusion model is not advanced enough, but the interaction design of those systems needs to be well-designed. A novel way of interaction is needed to harness the full potential of AI systems in order to serve as efficient design and creativity support tools. As Juho stressed in his talk, we need interaction-centric AI (*Juho Kim - Interaction-Centric AI | MIT CSAIL*, n.d.) to exploit the full potential of AI systems.

7.2. Future work

I will start building the design support systems based on the formative studies' findings. For instance, image AI could be implemented as plug-ins or a new AI feature in drawing applications like Procreate to assist early-stage design direction exploration. I envision in the future, designers could freely use large models like Stable Diffusion as well as utilize reinforcement learning to learn individual design styles. Combining the large-scale model's advantage of utilizing the large dataset and the advantage of tuning the model with niche style, hopefully, the designer could fully utilize the generative image AI to reduce the repetitive work while enhancing their creative competence.

Secondly, based on study 2's findings, I envision implementing an integrated platform like this website for synchronous design communication support that designers and users can collaborate on (see Image 22). Besides using the platform for supporting designer-client communication, I see other possible scenarios for using this platform. For instance, many users could use image AI to visualize and share their needs with the designer; designers could use the platform to ideate design ideas with other designers remotely, etc.

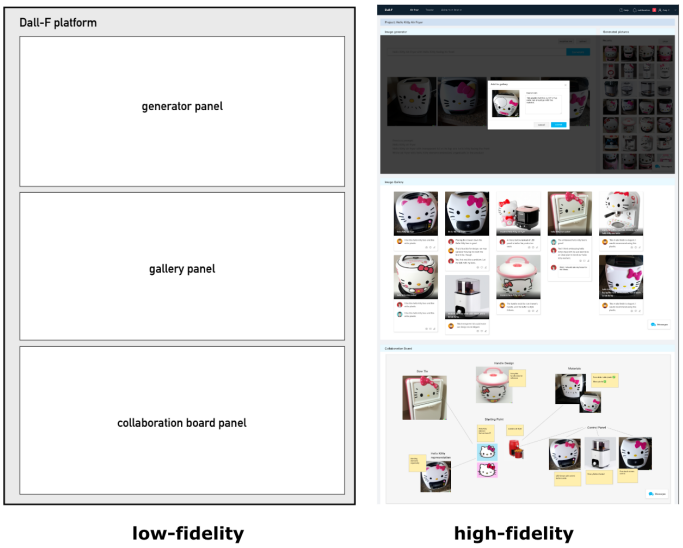


Image 22: Proposed system for bridging design communication

While the above-mentioned examples are only part of the possible future work directions, my end goal is to build efficient and versatile design and creativity support tools to **empower designers, democratize design efforts, and bridge design communication.**

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Appendices

A. Recruitment Questionnaire

The study aims to understand how designers use generative text-to-image AI tools to assist design practice, and how we can use these tools for design communication. We invite designers from various design domains and anyone who wishes to serve as a client for a design project to join our study. Each study lasts 80 min at most. You could choose one or more studies to attend. We will compensate for a $15 gift card for your time.

Q1: What kind of design work do you do? Or, do you want to be the client that someone designs for you?
☐ Architecture design
☐ Graphic design
☐ Product design
☐ Interior design
☐ Client (someone designs for you)
☐ Other _____

Q2: Are you a native English speaker? Or, do you match the following English testing requirement ?
☐ I am a native English speaker/I have bilingual fluency in English
☐ I matched the TOEFL 102 / IELTS 7.5 / Duolingo 120 criteria
☐ No, I don't match the above criteria

Q3: How many years have you studied and worked in your design domain in an English speaking country?
☐ 1-3 years
☐ 4-5 years
☐ 6+ years
☐ I wish to be the client(that someone designs for you)
☐ Other _____

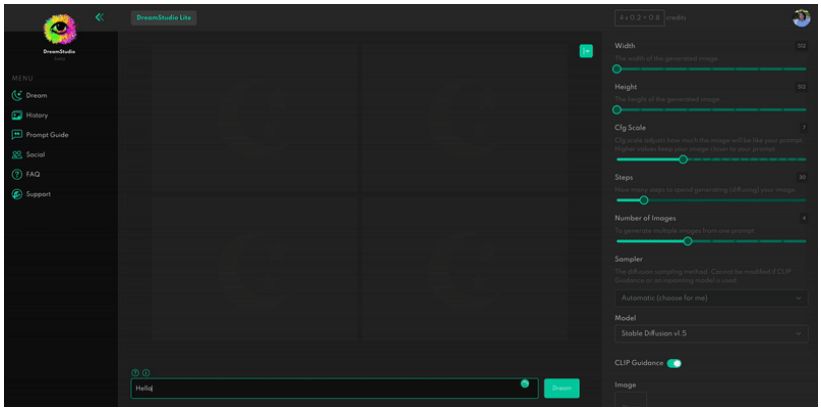
Q4: There are three studies each lasting one hour and you're invited to join one or more of these. Please indicate your preference:
☐ I wish to use the computer only in the workshop (Study1)
☐ I wish to draw(iPad and drawing materials provided) and use the computer in the workshop (Study2)
☐ I wish to be the designer, using the computer while communicating with the client in the workshop (Study3)
☐ Other

Q5: Please provide your email if you are interested in joining our study.
_____

B. Onboarding document

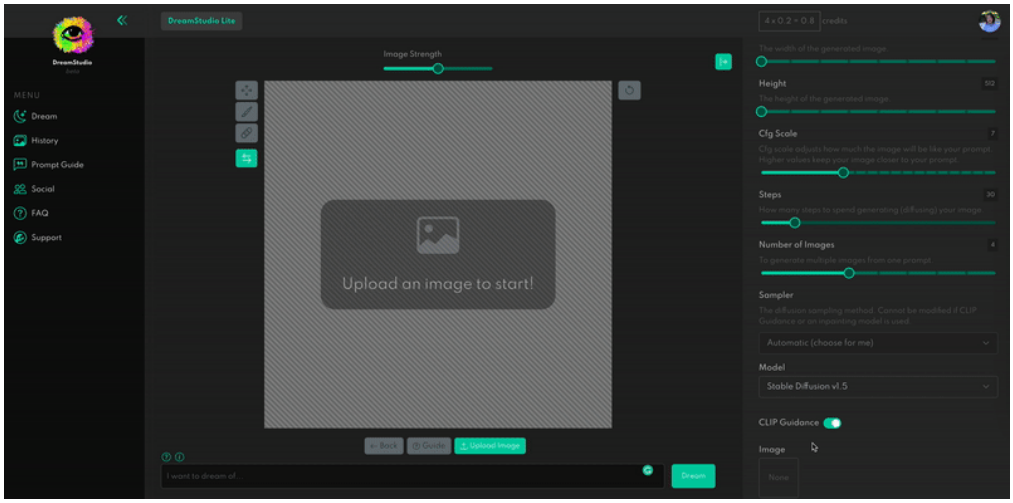
Case 1: text-to-image generation

1. Click this link(https://beta.dreamstudio.ai/dream) to open DreamStudio.
2. Enter the prompt into the text box at the bottom of the page and click the Dream **button** for generating images.



Case 2: Design sketch-to-image generation

1. Draw on the iPad and use **AirDrop** to send the picture to the computer.
2. Click this link(https://beta.dreamstudio.ai/dream) to open DreamStudio.
3. Click on the **Image button** in down right corner and select the design sketch you draw



4. Enter the prompt and hit the **Dream** button to generate images based on your sketch and the prompt.
5. Download the image to iPad using **Airdrop** and draw the overlay on the image

Example of Prompts and Images

Few words to describe	A modern kitchen	
More words to describe	An Instagram style modern design kitchen	
More detailed description	An Instagram style modern design kitchen with gold fixtures, dark blue cabinets, white tiles, and a farmhouse sink, professional picture.	

**Need more examples of how other designers use text caption to create design works? Click here: Lexica.art (https://lexica.art/)*

C. Interview Questions

Study 1

Number	**Topic**	**Question**
Q1	The experience	1.1 Based on your experience working with AI tools, do you think AI tools work well? Why? 1.2 (If yes) Which part of the AI tools do you think works well? Why?
Q2	The challenges	2.1 Have you encountered any challenges using this tool? 2.2 (If yes) What challenges did you encounter? How did you overcome/navigate through these challenges to get the outcome that you want? Why did they matter to you?

Q3	The improvement	3. Based on the challenges you encountered, in what ways could AI tools improve to better facilitate the early stage of your design processes?
Q4	Using the tool in the workflow	4.1 Imagine a recent project you've done(set the context). Would you like to incorporate the AI tool to your current practice? 4.2 (If yes) Will the workflow be better or worse? In which part do you think it will be better/worse? How would it change how you design? (If no) Why not? Can you tell me the reason why?

Study 2

Number	**Topic**	**Question**
Q1	The experience	1.1 Do you think AI tools work well? 1.2 (If yes) Which part of the AI tools do you think works well?
Q2	The challenges	2.1 Have you encountered any challenges using this tool? 2.2 (If yes) Which part do you think AI tools work well? Tell me about the experience challenges you encountered.
Q3	The improvement	3. Based on the challenges you encountered, what do you think AI tools could improve to better facilitate your design processes?
Q4	Using the tool in the workflow	4.1 [Client] Imagine you're communicating with a designer about the design needs. Would you like to incorporate the AI tool to facilitate design communication? [Designer] Imagine you're communicating with a client about your design. Would you like to incorporate the AI tool to facilitate design communication? 4.2 (If yes) Do you think it will be better for the design communication or worse? (If no) Why not? Can you tell me the reason why?
Q5	Sharing the prompt	5. Did you use each other's prompt? Did sharing the prompt help you with the design processes or not?

D. Demographic Questionnaire

Q1: Email _____

Q2: What's your participation number? _____

Q3: What's your gender
☐ Male
☐ Female
☐ Prefer not to say
☐ Other _____

Q3: How old are you? _____

Q4: Are you a design student or a professional designer?
○ Professional designer
○ Design student
○ I'm the client in the study
○ Other: _____

Q5: What's your current major/ job title? (Please be specific, like Master of Science in Computational Design, Senior Mechanical Engineer, etc.) _____

Q6: How many years have you **studied** in the design domain? _____

Q7: How many years have you **worked** in the design domain? _____

Q8: What tools do you usually use for design sketches?
☐ Drawing on the paper
☐ Hand-painted board
☐ iPad
☐ I seldom do design sketch
☐ Other: _____

Q9: How frequently do you do design sketches?
○ I seldom sketch
○ On a monthly basis
○ Several times a month
○ On a weekly basis
○ Several times a week
○ On a daily basis
○ Other: _____

Q10: How much experience do you have in design sketches?
○ No experience
○ A little
○ Some
○ A lot
○ Professional

Q11: How frequently do you use generative image AI?
○ I never used it before
○ I used it a few times
○ I use it on a monthly basis
○ I use it on a weekly basis
○ I use it on a daily basis

Q12: How many hours have you spent on generative image AI so far?
○ 0-1 hour
○ 1-5 hours
○ 5-10 hours
○ 10-30 hours
○ 30 hours +

Q13: Have you used generative image AI using any image as the input?
○ Yes
○ No