REFLECTING USERS' PHYSICAL CHARACTERISTICS IN SPATIAL VISUALIZATION

Sumin Chae, Hayoung Jo, Bomin Kim &Jin-kook Lee
Dept. of Interior Architecture & Built Environment, Yonsei University, Seoul, Republic of Korea

ABSTRACT: *This paper aims to quickly and precisely visualize remodeled design images based on image generation AI so that they can be used as alternative images in the early stages of design. In order to create a space image suitable for the user, the contents of the text are proceeded as follows. Bathrooms with many accidents in the space were selected as the target space, and users were designated as elderly people with many physical changes. Learning image data for additional training was self-generated according to the user's body characteristics, and the learning data focused on musculoskeletal aging among the body characteristics of elderly users. When the image was generated using additional training models, it was confirmed that a meaningful spatial image was created for musculoskeletal aging users, and it can be expected that the spatial image for spatial remodeling can be obtained quickly and accurately without the help of experts through subsequent studies to make it easier for general users.*

KEYWORDS: *Generative AI, Physical Characteristics, Elderly-friendly Bathroom, Detailed Modeling*

1. INTRODUCTION

This paper explores the integration of artificial intelligence (AI) technology into image generation during spatial remodeling and initial design phases. It aims to automate visualization for promoting safe space utilization by considering user's physical characteristics and to investigate various practical applications. Spatial visualization plays a crucial role in conveying design concepts and ideas visually to clients. However, generating visualizations for architectural spaces requires a significant amount of time and effort, and one alternative is to leverage image-generating artificial intelligence. By utilizing image-generating AI, detailed user input regarding spatial requirements can lead to the generation of corresponding space images.

To design safe spaces, it's essential to establish environments suitable for users and based on professional expertise, ensuring safety. However, this design process can incur costs such as labor expenses. Nonetheless, using generative AI allows for the efficient generation of trustworthy alternative space images by utilizing models trained on abundant data. Therefore, this study investigates an extended visualization approach in the field of architecture through image-generating AI. It focuses on generating a variety of personalized visualization alternatives for users, rather than presenting standardized alternatives.

2. BACKGROUND

2.1 Image Generation AI

The advancement of intelligent computing technology has brought about innovative changes in research methodologies and approaches within the field of architecture. Tools such as the architectural design assessment rule-checking system (Eastman, *et al*. 2009) and the spatial data-based building design review system (Lee, *et al*. 2012) have also been utilized. However, more recently, the rise of image-generating artificial intelligence (AI) technology has introduced significant transformations in the architectural realm. While previous studies primarily focused on the application of AI algorithms for predicting and optimizing architectural elements such as building appearance and interior composition, the present landscape is marked by image-generating AI technology providing fresh perspectives on visual representation and design in architecture. This influence extends not only to the architectural domain but also spans various other fields. For instance, within the medical sector, image-generating AI has been employed to analyze medical images and medical knowledge-based imagery (Kather, *et al*. 2022). Similarly, in the realm of arts, image-generating AI has found utility as a tool for creative artwork generation (Beyan, *et al*. 2023). This multifaceted application underscores the integration of image-generating AI across diverse domains, fostering ongoing research endeavors.

Furthermore, the focus of research has been directed towards leveraging artificial intelligence for performance optimization within the architectural context. Models powered by AI algorithms empower architects to experience energy efficiency within designs before the commencement of construction. This approach not only streamlines

Referee List (DOI: 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)
Sumin Chae, Hayoung Jo, Bomin Kim, Jin-Kook Lee, *Reflecting Users' Physical Characteristics in Spatial Visualization,* pp. 943-949, DOI 10.36253/979-12-215-0289-3.94

the design process but also contributes to sustainable and user-centric outcomes, fostering anticipations of substantial contributions. In essence, the amalgamation of AI technology with architecture is shaping novel research directions and enhancing both design methodologies and the conceptualization of architectural spaces.

2.2 Design of a space reflecting physical characteristics

Occupants continually modify and inhabit spaces to enhance comfort. Shifting demographics, family compositions, and evolving space roles often prompt interior modifications. Precision in incorporating users' physiological and psychological data into designs can significantly improve the quality of life by enhancing safety, usability, and independence (Demirbilek & Demirkan, 2004). For instance, designing spaces for individuals with disabilities necessitates collaboration between experts and users, ensuring their unique needs are met (Imrie, 2004). Similarly, creating spaces for children requires considerations such as play areas, noise control, and equipment tailored to their needs (Evans & Moch, 2003). Moreover, equipment scale within a space often deviates from conventional dimensions to harmonize with users' specific requirements. This departure from standardization not only influences the spatial arrangement but also distinctly shapes the manner in which objects are engaged within these environments.

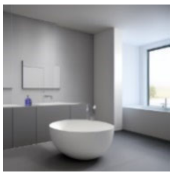
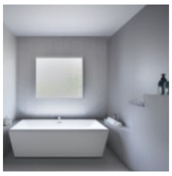
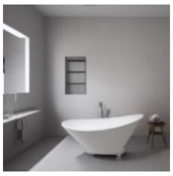
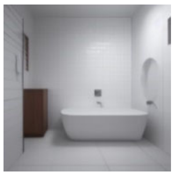
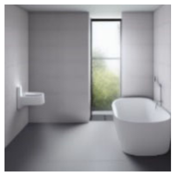
Within this multifaceted framework, it becomes acutely clear that the alignment of spatial configurations and amenities with the diverse physiological attributes of users is an imperative. This thematic focus is central to the present study, which delves into the meticulous curation of spatial layouts and equipment, meticulously calibrated to resonate with the myriad physiological attributes presented by users. This comprehensive endeavor stands as the foundation for establishing environments centered around the user, thus aiding in improving the overall quality of life.

3. AI-BASED SPATIAL IMAGE GENERATION

3.1 AI-Based Image Generation Test

To enhance satisfaction and facilitate convenient usage of spaces, appropriate improvements are essential. To achieve these improvements, a clear understanding of the users of the space is crucial. Furthermore, it is necessary to incorporate the layout and facilities of the space based on the users' physical characteristics. To generate spatial images based on these physical characteristics and reflect the users' desired points of improvement, a focused test was conducted. We tested image generation using the text-to-image functionality of the AI platform named Stable Diffusion (SD), which utilizes a Diffusion model. This involves using a deep learning model to generate images based on natural language input (Zhang, *et al*. 2023). In order to utilize SD, relevant prompts need to be formulated for the desired images. These prompts are categorized into Positive Prompts and Negative Prompts. Positive Prompts are crafted to enhance space types and image quality, while Negative Prompts are designed to prevent image degradation or errors. The image generation test focused on residential bathroom spaces, which often experience numerous accidents. In this test, not only were typical bathroom images in Korea generated, but also images tailored to the physical characteristics of elderly users, in an effort to ascertain if these factors were being considered. For this purpose, the generation of bathroom images was performed using image generation AI, with specific attention to bathrooms in domestic settings, particularly bathrooms prone to accidents. To ensure the consideration of users' physical characteristics, bathroom images that catered to the needs and safety of elderly individuals were generated alongside conventional bathroom images.

Table 1 Generating images by text

Standard bathroom	    
Positive prompt	A basic bathroom with a white porcelain toilet, a sink with a chrome faucet, and a standard bathtub with a showerhead. The walls are tiled with white rectangular tiles and the floor is covered with grey linoleum, Simple, clean, functional, standard, basic, minimalistic, bright lighting, plain, High resolution, sharp focus, realistic lighting, standard aspect ratio.
Negative prompt	Multiple layouts, avoid bright and clean elements, low quality, bad proportion, normal quality, watermark, bad perspective, confusing details, text, blurry

Musculoskeletal aging user bathroom	
Positive prompt	Musculoskeletal Aging, bathroom for the elderly, wall handrail attached, non-slip tile, perspective view, wide angle, Simple, clean, functional, standard, basic, minimalistic, bright lighting, plain, High resolution, sharp focus, realistic lighting, standard aspect ratio, standard.
Negative prompt	Multiple layouts, avoid bright and clean elements, low quality, bad proportion, normal quality, watermark, bad perspective, confusing details, text, blurry

3.2 Physical Characteristics-Based Training for Spatial Image Generation

Upon reviewing the generated images, it is evident that the spatial visualization capability is impressive; however, images are being generated without considering user conditions, required expertise, and specific situations. Observing the Korean-style bathroom images, the structure of a typical Korean apartment bathroom, including the sequence of toilet, sink, and shower booth/bathtub, is not reflected in the generated images. Instead, the images are generated with a focus on a single bathroom component, neglecting the holistic bathroom layout. In the case of elderly friendly bathroom images for older users, safety facilities should be reflected to prevent accidents when the elderly use the space. However, the generated image does not reflect the safety equipment properly, or, even if installed, the safety equipment is attached to a space other than the bathroom, generating a facility that is unsuitable for space conditions. Consequently, to utilize image-generating AI for generating

Elderly-friendly bathroom space images, an approach involving the addition of learned images that incorporate safety equipment in appropriate positions within the bathroom based on medical expertise and the physical characteristics of the elderly is required.

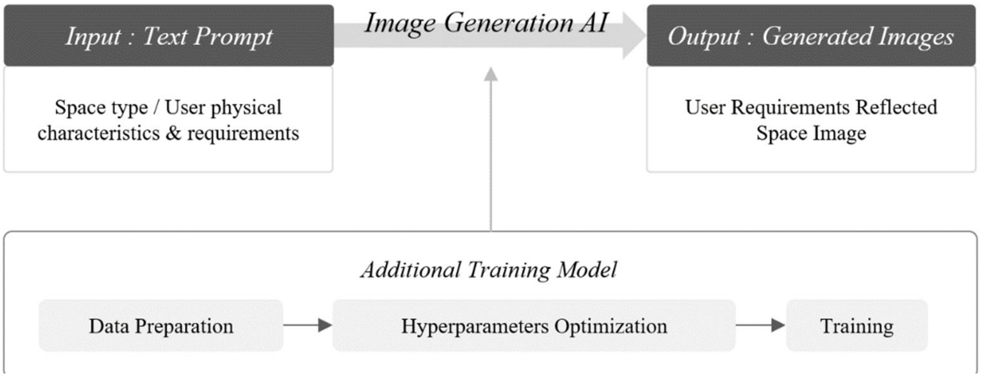


Figure 1 Summary of the configuration outlined in this study.

4. ADDITIONAL TRAINING FOR DESIGN COMPONENTS VISUALIZATION

4.1 Data preparation and Pre-processing

The datasets required for further training should comprise image files along with corresponding text descriptions. However, the available training images for Korean-style bathroom structures, obtainable from the current website, predominantly consist of wide-angle images to capture confined bathroom spaces. Consequently, even with additional training, the generated images might continue to emphasize wide angles or exhibit pronounced distortion. Furthermore, when considering bathrooms designed for elderly users, images depicting safety equipment installed by non-experts without professional knowledge outnumber those accounting for individualized physical characteristics. This discrepancy could potentially result in compromised safety and reliability. Therefore, the generation of image data conducive to effective learning is imperative.

Given this scenario, it becomes essential to independently generate image data specifically tailored to bathrooms for the elderly, considering their unique physical attributes. To accomplish this, a comprehensive exploration of

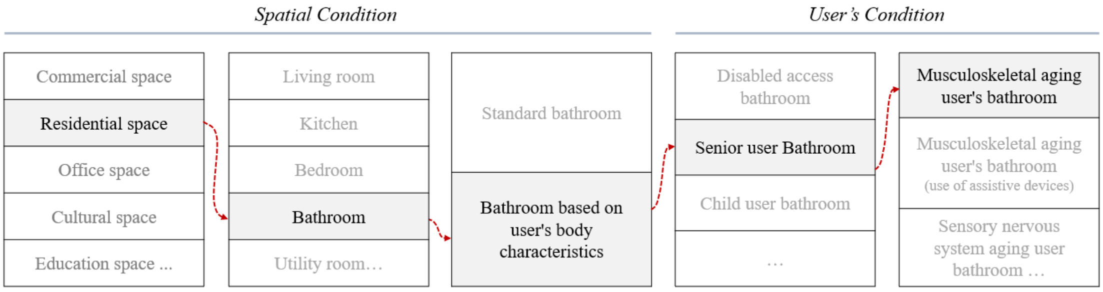


Figure 2 Scope of Work

bathroom layouts, incorporating safety equipment based on the aging characteristics of the elderly, is crucial. Additionally, the collection of fundamental components necessary for spatial Building Information Modeling (BIM) is paramount. In this paper, we have developed an additional training model that centers around musculoskeletal aging, a facet of the aging process significantly influenced by environmental factors and exerting significant effects. To ensure the safe use of the bathroom, safety equipment that can be installed includes bathroom grab bars, floor mats, shower chairs, and more(Gitlin, *et al*. 1999)(Aminzadeh, *et al*. 2000).

Table 2 Information about Properties of BIM Objects

N	*Bathroom facilities*	*Height (mm)*	*Width (mm)*	*Depth (mm)*	*N*	*Bathroom facilities*	*Height (mm)*	*Width (mm)*	*Depth (mm)*
1	A washbasin with a wide top	120	750	470	6	Walk-in bathtub	780	1150	930
2	Toilet wall grab bar	304	685	50	7	Draw-out faucet	220	505	273
3	Washbasin with chair	750	595	455	8	Folding shower chair	424	604	604
4	Nonslip floor	-	-	12.7	9	Bathtub/shower grab bar	889	482	50
5	Toilet side grab bar	300	100	738	10	Shower curtain	1803	107	80

<Table 2> represents a list of BIM objects for bathroom safety equipment collected for the purpose of BIM modeling. This list is a compilation of objects sourced either from the bimobject website, which offers downloadable objects for 3D modeling, or generated directly. The collected objects are categorized based on users' physical characteristic, bathroom areas, and expected effects. This categorization serves as the foundation for crafting content in the training text, enabling the generation of images in accordance with prompts entered by users during the image generation process. The contextual text concerning bathroom areas and anticipated effects will be utilized in the future for the individualized training of each object when they are added separately to the model.

Table 3 Categorization of Safety Facilities

Classification criteria		Bathroom facility BIM object									
		1	2	3	4	5	6	7	8	9	10
Aging characteristics	A-1. MA	●	●	●	●	●	●	●	●	●	●
Expectation effectiveness	B-1 Anti-slip				●						●
	B-2 Maintaining body temperature										●
	B-3 Smooth movement						●	●			
	B-4 Supporting device	●	●	●		●			●	●	
	B-5 Emergency call facility										
Bathroom area	C-1 Basin	●		●							
	C-2 Toilet		●			●					
	C-3 Bathtub						●	●			
	C-3 Shower booth								●	●	●
	C-4 Floor				●						
	C-5 Ceiling										
	C-6 Wall										

4.2 Additional Training

To facilitate further learning, a dataset for additional training model is established by modeling safety-equipped bathrooms suitable for each stage of aging that was previously generated<Figure 3>. This dataset encompasses

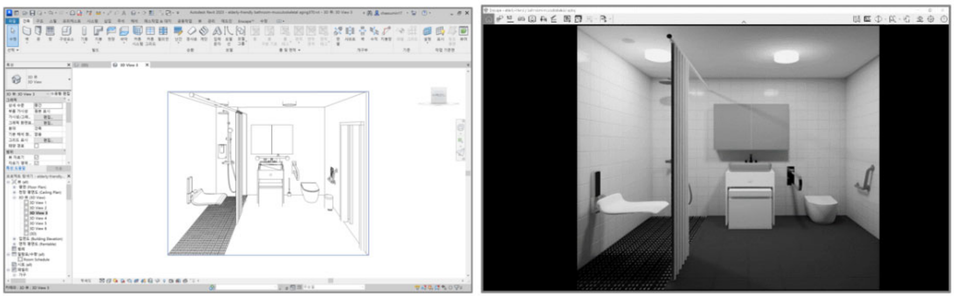


Figure 3 3D Space Modeling and Rendering

training image data sets and individual text files (.txt) associated with each image. These efforts are aimed at constructing a dataset for generating additional training models.

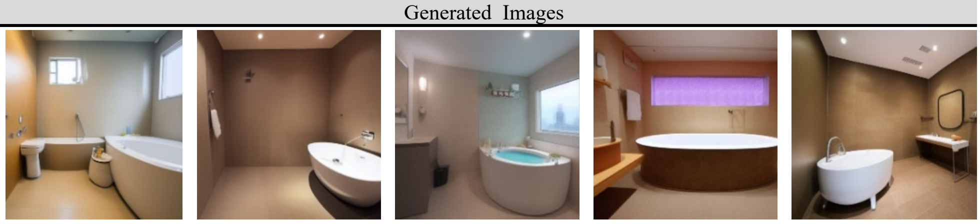
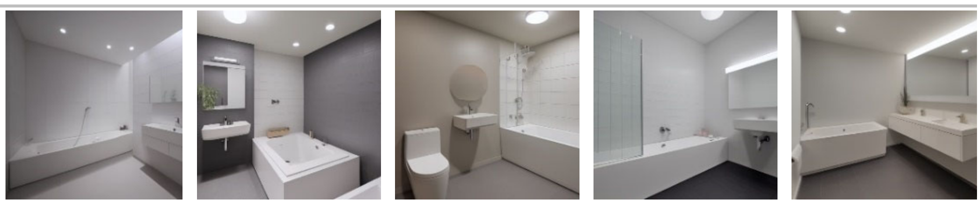
The generation of text files is facilitated through the utilization of BLIP Captioning within the Koha_ss GUI, an option found under Utilities. BLIP Captioning enables the individual generation of text files for a substantial number of images. For the task of further training, a LoRA model is generated employing Dreambooth-based LoRA GUI, Kohya_ss. LoRA, denoting Low-Rank Adaptation, effectively trains on high-quality images. The training settings for Dreambooth LoRA include parameters such as Train batch size: 1, Epoch: 120, Learning rate: 0.0001, Learning rate scheduler: cosine, and Learning rate warmup: 10. The model employs the Stable-Diffusion-v1.5 as a pre-trained model. The training environment was executed on a PC equipped with an RTX A6000 GPU model. Utilizing prepared training data, the model generation results in a .safetensors formatted model file of size 144MB.

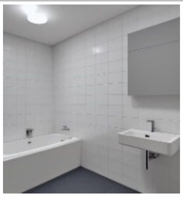
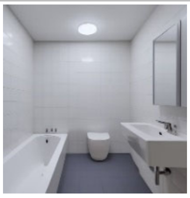
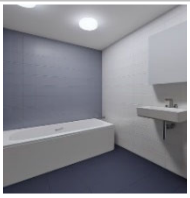
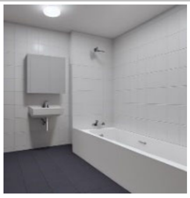
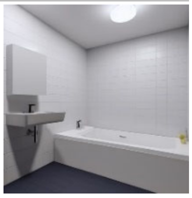
5. EVALUATION OF ADDITIONAL TRAINING MODELS

5.1 Evaluating Enhanced Model Performance

The manipulation of model weights in its application allows for varying degrees of reflection in the generated images. When prompts are entered, the LoRA augmented model, along with its associated weight, can be specified for incorporation, as illustrated in <Table 4> presenting the test images. The weight values, ranging from low 0 to high 1, facilitate a continuum of image representation. A weight value of 0 corresponds to an image where the model has not been applied, thus lacking the reflection of Korean-style bathroom structures and characteristics. Conversely, as the weight approaches 1, a gradual integration of Korean-style bathroom imagery becomes apparent.

Table 4 Generated image result according to model weight

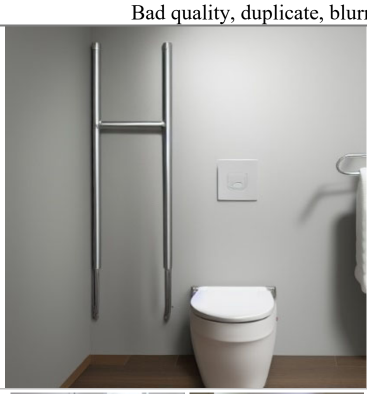
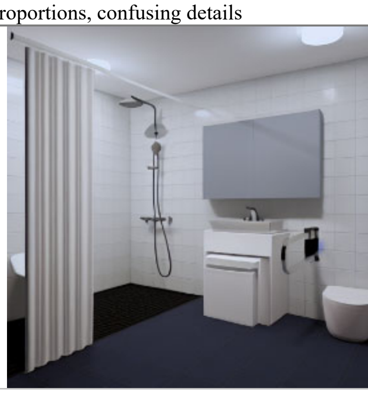
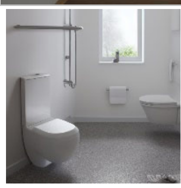
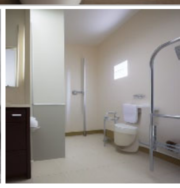
Weight	Generated Images
0.0	
0.3	

0.7					

5.2 Utilization Scenarios of the Additional Training Model

For the purpose of generating bathroom spatial design images based on physical characteristics, further training was conducted specifically focusing on age-related musculoskeletal changes. In the context of this study, a comparative analysis is carried out between images generated using the trained model and images generated without the utilization of the model. The intent is to contrast the images produced by the model-based approach with those produced independently, as illustrated in the table below.

Table 5 Comparing images for elderly users' bathrooms with/without extra models.

		Case A	Case B
Design Requirement	Space	Bathroom (Residential Space)	
	User physical characteristics	Musculoskeletal aging user	
INPUT	Model	N/A	Musculoskeletal aging user bathroom (.safetensor)
	Positive prompt	AIP_Elderly-friendly bathroom, Musculoskeletal aging, senior-friendly, senior housing, safety, fall prevention, bathroom, restroom, elderly, senior citizens, elderly users over 70, supporting device, device for safe toilet use, nonslip tile, toilet wall grab bar, toilet side grab bar, shower curtain, basin chair, folding chair	
	Negative prompt	Bad quality, duplicate, blurry, bad proportions, confusing details	
OUTPUT	Generated image		
		  …	  …

Overall, when comparing the generated images of Case A, which were produced without utilizing the augmented training model, with the images of Case B generated using the augmented training model, it becomes evident that Case A exhibits inaccuracies in the positioning and forms of the attached fixtures. Conversely, for Case B, where the augmented training model was employed, no errors are observed in the placement and forms of the safety equipment.

6. CONCLUSION

In conclusion, this paper explores the integration of AI in spatial remodeling and initial design stages with a focus on generating spatial images that reflect user physical characteristics. The objective is to provide users with safe spatial images, taking into consideration the user's physical attributes and real-world usage within the space.

Therefore, this paper targets the bathroom space and selects elderly individuals as the space users, aiming to generate safe bathroom images for seniors experiencing physical characteristics related to musculoskeletal aging through additional model training.

To facilitate additional training, suitable safety equipment for the user's physical aging characteristics was investigated, and high-quality training data were constructed by generating image data independently. Corresponding training text files were created for each image to ensure specific training for the images. As a result, it was observed that the images generated using the additional training model had fewer errors related to safety equipment compared to using the existing model, and suitable safety equipment was placed within the space, demonstrating a different outcome. This cost-effective approach recognizes the potential of AI in the field of spatial design, prioritizes a user-centric approach at the intersection of AI and architectural design, and advances and improves the design process. In addition to musculoskeletal aging, which was the focus of selecting elderly individuals as the target for additional training model creation in this paper, a comprehensive examination of aging occurring in various body structures or the selection of a more diverse range of subjects can expand the scope and target of additional training. Beyond simple visualization, this enables detailed spatial visualization based on user requirements through text input for image generation, which can be expected to be utilized in various fields for AI-generated images.

7. ACKNOWLEDGMENTS

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education (Grant NRF-2022S1A5A2A03053998)

REFERENCES

Aminzadeh, F., Edwards, N., Lockett, D., & Nair, R. C. (2000). Utilization of bathroom safety devices, patterns of bathing and toileting, and bathroom falls in a sample of community living older adults. Technology and Disability, 13(2), 95-103. 10.3233/TAD-2000-13202

Beyan, E. V. P., & Rossy, A. G. C. (2023). A Review of AI Image Generator: Influences, Challenges, and Future Prospects for Architectural Field. Journal of Artificial Intelligence in Architecture, 2(1), 53-65. https://doi.org/10.24002/jarina.v2i1.6662

Demirbilek, O., & Demirkan, H. (2004). Universal product design involving elderly users: a participatory design model. Applied ergonomics, 35(4), 361-370. https://doi.org/10.1016/j.apergo.2004.03.003

Evans, G. W., Wells, N. M., & Moch, A. (2003). Housing and mental health: a review of the evidence and a methodological and conceptual critique. Journal of social issues, 59(3), 475-500. https://doi.org/10.1111/1540-4560.00074

Eastman, C., Lee, J. M., Jeong, Y. S., & Lee, J. K. (2009). Automatic rule-based checking of building designs. Automation in construction, 18(8), 1011-1033. https://doi.org/10.1016/j.autcon.2009.07.002

Gitlin, L. N., Swenson Miller, K., & Boyce, A. (1999). Bathroom modifications for frail elderly renters: Outcomes of a community-based program. Technology and Disability, 10(3), 141-149. 10.3233/TAD-1999-10302

Imrie, R. (2004). Disability, embodiment and the meaning of the home. Housing studies, 19(5), 745-763. https://doi.org/10.1080/0267303042000249189

Kather, J. N., Ghaffari Laleh, N., Foersch, S., & Truhn, D. (2022). Medical domain knowledge in domain-agnostic generative AI. NPJ digital medicine, 5(1), 90. https://doi.org/10.1038/s41746-022-00634-5

Lee, J. K., Lee, J., Jeong, Y. S., Sheward, H., Sanguinetti, P., Abdelmohsen, S., & Eastman, C. M. (2012). Development of space database for automated building design review systems. Automation in Construction, 24, 203-212. https://doi.org/10.1016/j.autcon.2012.03.002

Zhang, C., Zhang, C., Zhang, M., & Kweon, I. S. (2023). Text-to-image diffusion model in generative ai: A survey. arXiv preprint arXiv:2303.07909.