

Voting-Based Intervention Planning Using AI-Generated Images

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The continuous evolution of artificial intelligence and advanced algorithms capable of generating information from simplified input creates new opportunities for several scientific fields. Currently, the applicability of such technologies is limited to art and medical domains, but it can be applied to engineering domains to help the architects and urban planners design environmentally friendly solutions by proposing several alternatives in a short time. This work utilizes the image-inpainting algorithm for suggesting several alternative solutions to four European cities. In addition, this work suggests the utilization of a voting-based framework for finding the most preferred solution for each case study. The voting-based framework involves the participation of citizens and, as a result, decentralizes and democratizes the urban planning process. Finally, this research indicates the importance of deploying generative models in engineering applications by proving that generative AI models are capable of supporting the architects and urban planners in urban planning procedures.

The Urban environments evolve dynamically aiming to improve the citizens' health and well-being. The continuous urbanization in combination with the poor design of the cities indicates critical issues that magnify further with the climate change hazards.¹ Heat stress, greenhouse gas emissions, air pollution, or flooding are some examples of the city challenges due to the combination of climate change and nonenvironmental friendly urban design.^{2,3}

Thus, urban regeneration based on environmentally friendly solutions can mitigate the climate change's negative effects.⁴ These solutions can include design policies for the reduction of traffic⁵ and the creation of green spaces.⁶

Architects, urban designers, and engineering experts play a critical role in urban regeneration by redesigning the urban environments considering nature-based solutions (NBS) to mitigate the impact

of climate change. In most cases, the design solutions depend on several factors, such as transportation, public/private spaces, socioeconomic, preserved/traditional areas, etc., which need to be considered during the design process.

Also, the several requirements of nonexperts, such as regional/local authorities, policymakers, and citizens, set challenges and difficulties that make the whole design process difficult and time consuming.⁷

To address these challenges and difficulties, machine learning and creative computing⁸ algorithms can be utilized for designing and implementing city management strategies. Artificial intelligence (AI)⁹ and affecting computing¹⁰ have also been investigated for urban planning applications. The continuous evolution of AI provides new tools that can be used as cutting-edge technologies for urban planning applications. An indicative example is the recently introduced generative AI technology based on diffusion models, which has already achieved significant results in creative art,^{11,12} and medical¹³ applications.

The innovation of the diffusion models¹⁴ is the generation of creative and visual compelling image synthesis from pure noise that opposes to traditional generative adversarial networks (GAN). This can be

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achieved by three distinct algorithms: (a) text-to-image (i.e., generate an image from a text description); (b) image-to-image (i.e., generate an image from another image and a text description); and (c) image-inpainting (i.e., change the selected pixels of an image by generating the pixel values based on a text description). These algorithms utilize the diffusion algorithm and transform the input into a pure noise image that gradually denoises to produce a new image. Currently, DALL-E,¹⁵ Stable Diffusion,^{16,17} and Midjourney¹⁸ provide competitive algorithms that can be used for different image synthesis applications.

This work proposes a novel methodology framework that can be used for assisting the architects and urban planners during the early stages of intervention planning. This framework utilizes the image-inpainting algorithm for generating several environmentally friendly solutions in four European cities, investigating the capabilities of generative AI diffusion models for urban design applications. The strong advantage of this technology is that it can produce several alternative solutions in a short amount of time. This feature actually formulates another problem, which is the evaluation of the several generated solutions.

Moreover, considering the fact that different people evaluate the same urban design solution differently, it is difficult to apply traditional AI evaluation metrics. To address these issues and evaluate appropriately the output solutions, we propose a voting-based system inspired by the emotion-based affective computing,^{19,20} for ranking the output solutions. The voting-system asks the opinion of several people, including both experts (i.e., architects and urban designers) and nonexperts (i.e., citizens). Considering the fact that emotions play a critical role on voting,^{21,22} the voting-based system includes by default the subjective emotion-related parameters. In addition, due to the fact that the voting process includes the opinion of both experts and nonexperts and involves people of different ages, educational background, etc., it promotes the public participation in the intervention planning, which democratizes and decentralizes the intervention planning procedures from the early stages, providing the necessary information to the architects and urban planners to design widely accepted solutions.

The rest of this article is organized as follows. (a) The "Literature Review" section investigates the current related works. (b) The "Proposed Methodology" section describes the proposed methodology. (c) The "Case Studies Analysis and Results" section demonstrates the proposed methodology into four European city pilots. (d) The "Discussion" section

summarizes the main insights of this work in a short discussion. (e) Finally, the "Conclusion" section concludes this article.

LITERATURE REVIEW

The rapid evolution in computer science and especially in AI domain introduced the generative AI models. These models are capable of generating high-quality images of astounding art and creativity,²³ signaling a new era in these domains. An example of such models is the CreativeGAN that is proposed in the work of Nobari et al.²⁴ for generating novel designs based on GAN models. Imagen is another example proposed by Saharia et al.²⁵ It utilizes text-to-image diffusion models for generating photorealistic images.

Although generative models of several architectures exist since 2018,²⁶ their applicability is limited to art and creativity.²⁷ Modern generative AI architectures introduce Stable Diffusion algorithms combined with an interactive web UI, introducing the web-based AI painting generator²⁸ as applications for empowering artists and creative designers. More advanced algorithms permit also the video generations, such as the text-to-video²⁹ algorithm, which is recently introduced for advancing further the artistic and creative synthesis.³⁰

Outside the art and creative domains, generative AI technology is utilized in medical science,^{31,32,33} MI-GAN is an indicative example of a generative algorithm, which is proposed by Iqbal and Ali³⁴ for generating several synthetic medical images and their segmented masks for creating a dataset capable to be used for applications regarding supervised analysis of medical images. Other applications of generative AI in medical science³⁵ consider disease detection, diagnosis, and screening processes.

Considering the creative and artistic characteristics of these technologies, it is worth discussing the utilization of generative AI in the intervention planning domain for assisting the architects and urban planners. Compared to creativity, art, and medical domains, there are limited works discussing this matter. Luccioni et al.³⁶ utilized GAN models for visualizing the impact of climate change in urban environments, while Phillips et al.³⁷ examined the applicability of stable diffusion in urban design, stating the need to provide additional works on this domain. Finally, Omar et al.³⁸ used generative AI approaches for calculating the sunlight access in urban spaces. In this work,³⁹ the utilization of generative AI algorithms, such as image-to-image and image-inpainting, for generative design applications is also investigated to assist the

architects and urban planners during the intervention planning procedures.

These technologies can be proved useful in intervention planning, by empowering the state-of-the-art computer-aided design,^{40,41,42} (CAD) software. Generative AI algorithms can also empower 3-D simulators based on virtual and augmented reality,^{43,44} by the introduction of 3-D generative models.^{45,46} In addition, generative algorithms,³⁹ such as image-to-image and image-inpainting, are capable of generating several alternative solutions in a short amount of time, assisting the experts by providing brainstorming ideas since the early stages of intervention planning.

Finally, these technologies can be deployed over existing software utilizing generative systems⁴⁷ technologies, empowering their current capabilities.⁴⁸

Summarizing the literature review, the utilization of generative AI image synthesis in intervention planning is lacking the necessary research, thus it is still an open topic for investigation. Currently, most of the generative AI related works emphasize its utilization for artistic, creative, or medical image synthesis. Although generative AI technology has proved useful in these domains, their investigation for architectural, urban planning, and engineering application is limited. This work aims to contribute to this topic by investigating the capabilities of generative AI for intervention planning applications. Thus, the contribution of this article is presented below.

- 1) This article introduces a novel framework for intervention planning based on a generative AI algorithm named image-inpainting as an assistive tool for architects and urban planners.
- 2) During the experimentation, it is observed that the main advantage of this methodology, which is the generation of several alternative visual solutions, formulates another problem regarding the evaluation of the results generated.
- 3) For addressing this issue, the proposed methodology is expanded accordingly by proposing and utilizing a voting-based framework for applying a score to the generated solutions and ranking them (i.e., finding the most preferred solution).
- 4) The voting-based system involves the participation of several people with different characteristics (i.e., age, education, experts/nonexperts, etc.); thus, the overall proposed methodology promotes the public participation to the intervention planning procedures, which democratizes and decentralizes the planning process.
- 5) The proposed methodology is implemented experimentally to four real case studies,

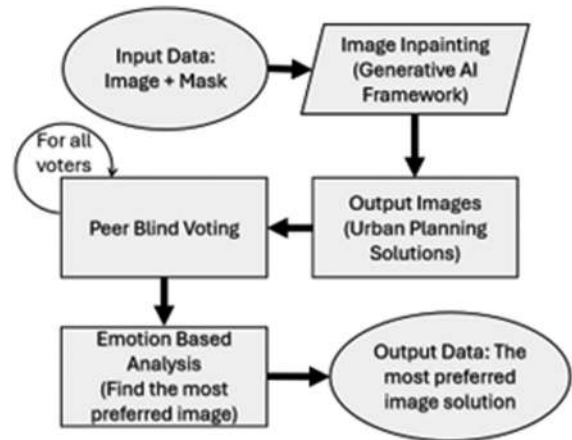


FIGURE 1. Architecture of the proposed methodology.

indicating the advantages and limitations of current generative AI models. In addition, this article suggests possible future work for addressing the observed limitations.

PROPOSED METHODOLOGY

This work proposes a framework to assist architects and urban environments based on generative AI image synthesis. In addition, an emotion-based approach for evaluating the generated solution is suggested. This is achieved by asking the opinion of both expert and nonexpert people. Each opinion is expressed by comparing all possible image pairs (pairwise voting) and using the preference score. For achieving maximum precision, the voting results are hidden until the vote of the last participants (i.e., secret voting). For the case studies of this article, 25 people were involved. These people cover a wide range of parameters, such as age, education, and relations with architectural and urban design applications (i.e., experts and nonexperts).

Figure 1 illustrates the architecture of the proposed methodology framework. The input data vary based on the selected generative algorithm: (a) text-to-image input: text description; (b) image-to-image: image + text description; and (c) inpainting-image: image + image mask + text description. The output of the generative process is a number of images, which are defined by the user at some point. Thus, the generative process is repeated until the user is satisfied with the number of the generated solutions.

Let us denote as N the size of the generated images, $\vec{I} = (I_x, I_y)$ a vector representing a pair of images I_x and I_y , and $g(\vec{I})$ a binary function, which

represents the voting results: 0 for selecting the I_x and 1 for selecting the I_y . Now, let us suppose that the starting image order does not change along with the voting process (i.e., $I_0, I_1, I_2, \dots, I_{N-1}, I_N$). Then, for each image with index $i = 0, 1, 2, \dots, (N-1), N$, we can define a score using the following equation:

$$\text{Score}(I_i) = \sum (g(I_i, I_y) \equiv 0) \mid \sum (g(I_x, I_i) \equiv 1). \quad (1)$$

However, each image can be voted $(N-1)$ times, thus the voting score is defined using the following equation:

$$\text{VotingScore}(I_i) = \frac{\text{Score}(I_i)}{N-1}. \quad (2)$$

The evaluation of the images is based on the average voting score (AVS). Let us denote as M , the size of the group of participants in the voting process. Then, for each image I_i , the AVS is calculated by adding each individual $\text{VotingScore}(I_i)$ and dividing by M as presented in the following equation:

$$\text{AVS}(I_i) = \frac{\text{VotingScore}(I_i)}{M}. \quad (3)$$

Finally, the solutions can be ordered by the most to least preferred based on the value of AVS. The most preferred solution's AVS value is closer to 1, while the least preferred AVS value is closer to 0. By applying this voting process to the methodology, the whole design process is democratized and decentralized. Moreover, by using the inpainting-image generative AI algorithm, each solution can be applied and visualized in the area of interest.

CASE STUDIES ANALYSIS AND RESULTS

Case Study 1: Linear Park (Belgrade, Serbia)

The Linear Park project in Belgrade entails the development of a new park area by repurposing a defunct railway track extending from the former industrial storage facility "Betonhala" to the Pancevo Bridge on the Danube River. This park traverses varied urban landscapes, ranging from the organized and bustling areas beneath the Belgrade fortress to the deteriorating sections of the Port of Belgrade industrial zone. Consequently, this urban area requires revitalization through a range of activities aimed at enhancing its appeal and attracting greater footfall from visitors to this part of the city.



FIGURE 2. Visualization of the current situation of a square in the Linear Park region (source: Google Street View).

Figure 2 illustrates the current situation of a square in the Linear Park region from Google Street View. A possible architectural regeneration considers the addition of green areas (i.e., trees, flowers, etc.), fountains, benches, etc. An NBS architecture design will upgrade this part of the city, attracting citizens for several activities, such as walking, reading, relaxing, etc. The final result aims to address the needs of the stakeholders and increase the human health and well-being of the visitors to this part of the city.

According to the proposed methodology, the Stable Diffusion image-inpainting algorithm was utilized for generating five alternative solutions. For generating the solutions, it was asked to the AI to design environmentally friendly interventions with a fountain for attracting the citizens of Belgrade city to visit the depicted area. The output of the AI method is visualized in Figure 6, and Table 1 presents the voting scores of the 25 participants, including the AVS, which is used for deciding the most preferred solution.

After generating the image solutions, it was asked to the 25 voters, who include both experts and nonexperts of a variety of ages, to vote for the most preferred solution in the same terms. To be precise, the criteria given for evaluating the solutions in this case study were to vote for the most preferred of two images, considering that both solutions are applicable and in which intervention planning would visit the most.

TABLE 1. Belgrade's solutions voting scores of 25 voters and AVS.

Voter ID	VS_0	VS_1	VS_2	VS_3	VS_4
00	0.25	0.50	1.00	0.75	0.00
01	0.50	1.00	0.75	0.00	0.25
02	0.50	0.50	0.50	0.25	0.75
03	0.25	0.50	0.75	0.25	0.75
04	0.75	0.50	1.00	0.00	0.25
05	0.75	0.50	1.00	0.00	0.25
06	0.50	0.00	0.75	0.25	1.00
07	0.50	0.25	0.00	1.00	0.75
08	0.00	0.25	0.75	0.50	1.00
09	0.25	1.00	0.50	0.00	0.75
10	0.00	1.00	0.75	0.25	0.50
11	0.25	0.25	1.00	0.25	0.75
12	0.75	0.50	1.00	0.25	0.00
13	0.75	0.50	0.75	0.00	0.50
14	0.00	0.50	1.00	0.25	0.75
15	0.00	0.50	1.00	0.25	0.75
16	0.50	0.50	0.75	0.75	0.00
17	0.25	0.75	1.00	0.00	0.50
18	0.00	0.25	1.00	0.50	0.75
19	0.00	0.50	0.75	1.00	0.25
20	0.50	0.00	1.00	0.75	0.25
21	0.50	1.00	0.25	0.00	0.75
22	0.25	0.00	1.00	0.50	0.75
23	0.25	0.00	1.00	0.75	0.50
24	0.25	0.00	0.75	0.75	0.75
AVS	0.34	0.45	0.80	0.37	0.54

Table 1 summarizes the voting results. In this case scenario, the third image (Solution 2) scored 0.80 AVS value, while the second in rank is the fifth image (Solution 4) with a score of 0.54. Thus, it is safely assumed that a solution similar to the third image, as illustrated in Figure 6, or similar alternatives can be a solution.

Case Study 2: Pileparken (Gladsaxe, Denmark)

Social housing homes are a common policy in Denmark. About half a million social housing homes are currently available. This policy refers to everyone;



FIGURE 3. Visualization of the parking in the middle of the four-apartment block of Pileparken (source: Google Street View).

however; there are some constraints and special obligations toward population groups with housing needs. For example, young students, the elderly, people with disabilities, single parents, and refugees are possible and immediate candidates. Pileparken region is a social house estate built in 1969 and renovated in 2010. Currently, it contains four apartment blocks (117 apartments and approximately 1700 inhabitants). Figure 3 illustrates the parking area of Pileparken. In this area, green areas will be developed as a solution for addressing the huge amount of rainwater (i.e., flooding issues) by evaporation. In this demonstration, it is asked by the AI to build a park with green spaces and possibly a fountain for addressing the issue of rainwater and provide a harmonized environment to the inhabitants for possible walking, communicating, and promoting other activities that can increase their health and well-being.

The output solutions of the generative AI algorithm are visualized in Figure 6. Table 2 presents the scores of the 25 voters and the final AVS, which is used for indicating the most preferred solution. In this case, the third image (Solution 2) was voted as most preferred solution with an AVS score of 0.65; however, it is worth noting that the fifth image (Solution 4), which is the second in line, has an AVS score of 0.64. Considering that the AVS difference between these images is almost 0, it can be assumed that either of these solutions can be

TABLE 2. Gladsaxe's solutions voting scores of the 25 voters and AVS.

Voter ID	VS_0	VS_1	VS_2	VS_3	VS_4
00	0.25	0.50	1.00	0.25	0.50
01	0.25	0.00	0.75	0.50	1.00
02	0.50	0.50	0.75	0.00	0.75
03	0.50	0.00	0.75	0.50	0.75
04	1.00	0.25	0.50	0.00	0.75
05	0.75	0.50	0.50	0.25	0.50
06	0.75	0.25	0.50	0.00	1.00
07	0.50	1.00	0.75	0.00	0.25
08	1.00	0.50	0.50	0.00	0.50
09	1.00	0.50	0.75	0.00	0.25
10	0.25	0.00	0.75	0.50	1.00
11	0.75	0.00	0.50	0.50	0.75
12	0.75	0.00	0.50	0.50	0.75
13	0.75	0.50	1.00	0.00	0.25
14	0.00	1.00	0.25	0.75	0.50
15	1.00	0.50	0.75	0.00	0.25
16	1.00	0.25	0.50	0.00	0.75
17	0.25	0.00	1.00	0.50	0.75
18	0.00	0.75	0.75	0.75	0.25
19	0.25	0.25	0.25	0.75	1.00
20	1.00	0.25	0.75	0.00	0.50
21	0.75	0.00	0.25	1.00	0.50
22	0.50	0.00	0.50	0.50	1.00
23	0.25	0.00	1.00	0.50	0.75
24	0.25	0.00	0.75	0.75	0.75
AVS	0.57	0.30	0.65	0.34	0.64

applied as a real intervention and be accepted equally by the citizens.

Case Study 3: Pasaz Anny Rynkowskiej (Lodz, Poland)

Pasaz Anny Rynkowskiej is a neighborhood in Lodz. This area is surrounded by dense tenement buildings and more extensively developed postindustrial (i.e., former factories). In the center of these buildings, there are pathways with some trees, but the whole area lacks any means of attracting the inhabitants for possible activities (e.g., walking, sitting on benches and communicating, etc.).



FIGURE 4. Visualization of the parking in the middle of the four-apartment block of Pileparken (source: Google Street View).

Figure 4 illustrates the current state of one of the pathways. Currently, there are some benches and a little space for greenery; however, the environment cannot inspire the citizens to stay for long. In this demonstration, it is asked to the algorithm to generate green areas, including trees, flowers, benches, and possibly a playground.

In this case study, the third solution (Solution 2) is also voted as the most preferred solution with an AVS score of 0.78, as presented in Table 3 and illustrated in Figure 6. However, it is worth noting that the second preferred solution, the second (Solution 1) and fourth (Solution 3) are close to each other with AVS scores of 0.59 and 0.60, respectively. Moreover, by observing carefully all the solutions of this case study, the generation of the images is not following exactly the given solution; however, the AI is struggling to generate solutions close to the text-prompt description. This is because the area is long and narrow; thus, both the image and the corresponding mask are not providing enough space for the AI to design architectural complex solutions.

Case Study 4: Dilaveri Coast (Piraeus, Greece)

Dilaveri Coast is a riverine inland area attracting many visitors due to the existing restaurants and cafeterias. However, this area is completely lacking green spaces, such as parts, which creates a huge

TABLE 3. Lodz solutions voting scores of the 25 voters and AVS.

Voter ID	VS_0	VS_1	VS_2	VS_3	VS_4
00	0.00	0.50	1.00	0.75	0.25
01	0.25	0.50	1.00	0.75	0.00
02	0.25	0.25	0.50	1.00	0.50
03	0.50	0.50	0.75	0.75	0.00
04	0.75	0.50	1.00	0.25	0.00
05	0.25	0.25	0.75	0.50	0.75
06	0.25	0.75	0.75	0.75	0.00
07	0.00	0.50	0.50	0.50	1.00
08	0.50	0.25	1.00	0.75	0.00
09	0.25	1.00	0.75	0.00	0.50
10	0.25	0.75	0.50	1.00	0.00
11	0.50	0.75	0.25	1.00	0.00
12	0.25	0.50	1.00	0.00	0.50
13	0.00	0.50	0.75	0.25	1.00
14	0.25	0.50	1.00	0.75	0.00
15	0.25	1.00	0.50	0.75	0.00
16	0.00	0.75	1.00	0.25	0.50
17	0.00	0.75	0.75	0.75	0.25
18	0.25	1.00	0.75	0.00	0.50
19	0.00	0.25	1.00	0.75	0.50
20	0.00	0.25	1.00	0.75	0.50
21	0.25	0.50	0.75	1.00	0.00
22	0.25	1.00	0.75	0.50	0.00
23	0.25	0.50	0.75	1.00	0.00
24	0.00	0.50	0.75	0.25	1.00
AVS	0.22	0.59	0.78	0.60	0.31

issue for the area. During the summer months, the area is too hot (i.e., extreme heat stress) to stand, even if it is close to the sea. For this reason, it is necessary to provide shading regions to this area and generally apply NBS interventions for mitigating the heat stress phenomenon.

Figure 5 illustrates a possible space for creating a small park (i.e., pocket park). This park will provide shading areas from trees. Moreover, a fountain in the middle can help in cooling the air in the park. Some benches and possibly a playground can attract visitors to the park area. This architectural design can provide health and well-being by mitigating the heat stress effect.



FIGURE 5. Visualization of a parking in Dilaveri coast (source: Google Street View).

The generated solutions are visualized in Figure 6 and the voting results are presented in Table 4. In this case, the most preferred solution based on the AVS score is the fourth (Solution 3) image with a score value of 0.79. The second image is the first (Solution 0) with an AVS score of 0.55. By observing carefully the solutions generated, it is worth mentioning that all the solutions are not applicable as they are. However, the voting results provide useful insights to the architect(s) that will undertake the intervention planning project.

Solutions' Summary

In Figure 6, the AI generated solutions per case study are illustrated. The most voted images are outlined with red color and their selection criteria are described in previous paragraphs. The following paragraphs provide additional information regarding the technical specifications of the systems as long as some major comments that many voters indicated regarding the solutions, during the secret voting process.

For the execution of all the necessary processes, two different GUI applications were developed using Python and generative models provided by the HuggingFace repository.¹⁷ The first application is called "AI Image Generator"⁴⁹ and is responsible for generating the image solutions. For the application to run smoothly, it is necessary to have installed the CUDA Toolkit of NVIDIA.⁵⁰ For effectively testing the utilities

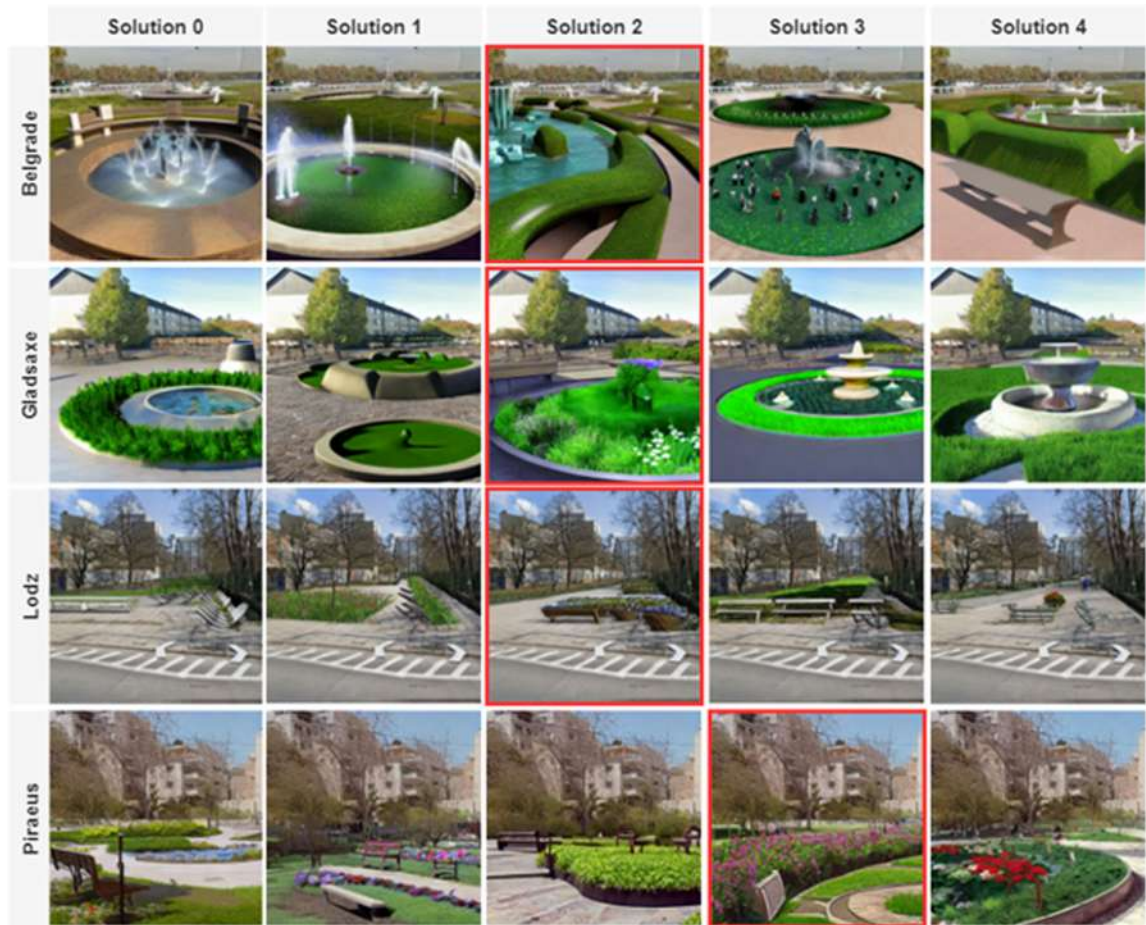


FIGURE 6. Summary of the generated solutions per case study. The images outlined with red lines correspond to the most voted solution.

of the image generation, we used three different devices equipped with the following features: (a) Device 1: NVIDIA GeForce GTX 1060 6GB and 32GB RAM; (b) Device 2: NVIDIA GeForce RTX 4060 8GB and 16GB RAM; and (c) Device 3: NVIDIA GeForce RTX 3070 Ti 8GB and 64GB RAM.

Table 5 presents the time needed for generating a photorealistic image of resolution 256×256 between the devices and in comparison with an architect's needed time.

Moreover, after the secret voting, it was asked to the voter how they rated the overall experience and how would they feel about the solutions being generated by the AI. Most of the voters were both enthusiastic and skeptical about the fact that the AI could produce such results. This behavior is observed mostly in the nonexperts rather than the experts, who have more experience with technological achievements. The experts commented more on

the solutions and agreed that the AI may be able to produce such results; however, it is far from generating a correct architectural composition solution. This comment is very important, especially on this secret voting, because it indicates and proves that generative AI technology can be used by the architects or urban planners as an assistive tool, but it cannot replace the experts.

AI-ASSISTING TECHNICAL ANALYSIS

In this point, it is worth noting that the quality of the images produced is low, and the ideas generated need a technical analysis. An interesting extension to this case study involves an AI-assisting technical analysis to the most voted solutions. For this analysis, the ChatGPT 4.0 model is considered as a powerful tool that thousands of people use every day for different

TABLE 4. Lodz solutions voting scores of the 25 voters and AVS.

Voter ID	VS_0	VS_1	VS_2	VS_3	VS_4
00	1.00	0.50	0.00	0.75	0.25
01	0.50	0.75	0.25	0.75	0.25
02	0.75	0.00	0.50	0.75	0.50
03	0.00	0.25	0.50	0.75	0.50
04	1.00	0.25	0.75	0.50	0.00
05	0.50	0.00	0.25	1.00	0.75
06	1.00	0.25	0.25	0.75	0.25
07	0.75	0.00	0.75	0.75	0.25
08	0.75	0.75	0.00	0.75	0.25
09	0.50	0.75	0.00	1.00	0.25
10	0.75	0.00	0.50	1.00	0.25
11	0.75	0.25	0.75	0.75	0.00
12	0.50	0.50	0.25	0.75	0.50
13	0.00	1.00	0.25	0.50	0.75
14	0.50	1.00	0.00	0.75	0.25
15	0.50	0.75	0.25	1.00	0.00
16	0.75	0.00	0.25	1.00	0.50
17	0.50	0.75	0.50	0.50	0.25
18	0.50	0.00	0.25	1.00	0.75
19	1.00	0.75	0.25	0.50	0.00
20	0.25	0.50	0.00	1.00	0.75
21	0.50	0.75	0.00	0.25	1.00
22	0.25	0.75	0.00	0.75	0.75
23	0.25	0.50	0.00	1.00	0.75
24	0.00	0.50	0.25	1.00	0.75
AVS	0.55	0.46	0.27	0.79	0.43

applications. The following paragraphs provide the technical analysis of ChatGPT 4.0 for each most voted solution.

Belgrade—Solution-2: The proposed design presents a modern, organic integration of curved green seating, water features, and geometric elements, offering both aesthetic appeal and functional urban space. Structurally, it requires careful material selection to ensure durability, load-bearing capacity, and waterproofing, while accessibility must be prioritized with ADA-compliant pathways and antislip surfaces for safety. The seamless curves and integrated greenery suggest a complex fabrication process, likely requiring custom precast concrete or

TABLE 5. Time duration for generating a photorealistic image of resolution 256×256.

Generating platform	Time per image	Images per hour
Architect	1–4 h	Max 1
Device 1	20.75 min	3
Device 2	11.50 min	5
Device 3	3.25 min	18

modular components. Implementing real grass in seating areas would pose maintenance challenges, favoring artificial turf or green roof systems with irrigation. The water feature’s sustainability depends on proper circulation, filtration, and drainage to prevent stagnation, and urban infrastructure constraints, such as soil conditions and climate, may influence feasibility. While the concept is visually cohesive, long-term maintenance, material longevity, and hydraulic efficiency must be considered to balance aesthetics with practicality, adjusting where necessary for a realistic and implementable solution.

Gladsaxe—Solution-2: The proposed design features a circular urban garden with lush vegetation, integrating greenery into a public space for both aesthetic and ecological benefits. Structurally, the raised planter requires durable materials, such as concrete or metal for long-term stability, along with proper soil depth and drainage systems to support plant health. Accessibility considerations should include barrier-free edges and seating areas to enhance usability. The realism of this design depends on plant selection, ensuring that species thrive in local climatic conditions with minimal maintenance. Irrigation and water management are crucial for sustainability, favoring rainwater harvesting or automated drip systems. While visually appealing and environmentally beneficial, the design’s feasibility relies on strategic plant choices, proper maintenance, and structural integrity to ensure longevity and practical implementation.

Lodz—Solution-2: The proposed design integrates modern urban furniture with green infrastructure, featuring elegantly curved wooden benches and planters filled with colorful flowers along a pedestrian pathway. Structurally, the benches and planters likely use durable, weather-resistant materials, such as treated wood or metal, ensuring longevity in outdoor conditions. The placement enhances the pedestrian experience, offering seating while maintaining open walkway circulation. Accessibility considerations should include



FIGURE 7. AI-generated scenarios for Belgrade and Gladsaxe (demonstration using different scenarios).

proper spacing between elements to accommodate wheelchair users and ensure unobstructed movement. The realism and implementability of the design depend on material selection, anchoring techniques for stability, and plant species suited to local climate conditions for low-maintenance upkeep. While aesthetically harmonious with its surroundings, the success of this concept hinges on balancing durability, accessibility, and sustainable maintenance to ensure its practicality in real-world urban spaces.

Piraeus—Solution-3: The proposed design effectively integrates green spaces with the surrounding urban environment, enhancing aesthetics, air quality, and pedestrian comfort through well-placed landscaping, walkways, and seating areas. It maintains architectural coherence with nearby buildings, creating a visually appealing and functional public space. However, its realism and implementability depend on factors, such as material selection, construction feasibility, and environmental adaptation. While the vibrant greenery and structured pathways suggest an idealized vision, maintaining such a landscape requires significant resources, particularly in extreme climates. Key considerations include accessibility compliance, long-term vegetation upkeep, proper drainage, and adherence to urban zoning regulations. If the design relies on artificial enhancements or idealized vegetation density, adjustments may be necessary to align it with real-world constraints while preserving its intended aesthetic and functional benefits. With refinements in material

durability, structural integrity, and sustainability measures, the project appears feasible and well suited for urban enhancement.

Summarizing this section, according to ChatGPT 4.0 analysis, all generated solutions seem feasible; however, technical characteristics, such as the material of structures or the foliage type for plants, need to be considered. Extending further this study and evaluating the technical analysis of ChatGPT 4.0, it is worth noting that explainable AI capabilities of these models are capable of assisting architects, urban planners, civil engineers, and general engineers in the renovation and construction field. By this point, it is clear that the assumption of using AI-driven technologies based on text prompts as assistive tools is proved. However, further research and development is necessary to mitigate the impact of uncharted limitations so far.

EVALUATING THE ROLE OF TEXT PROMPTS IN GENERATING URBAN PLANNING SOLUTIONS

Before discussing the main points of this article, it is important to provide additional examples using more descriptive text prompts for: (a) proving that the algorithm is working for several different applications, and (b) examining the behavior of the model under different descriptions. Figures 7 and 8 illustrate different solutions for the four euPOLIS cities using the following text prompts.

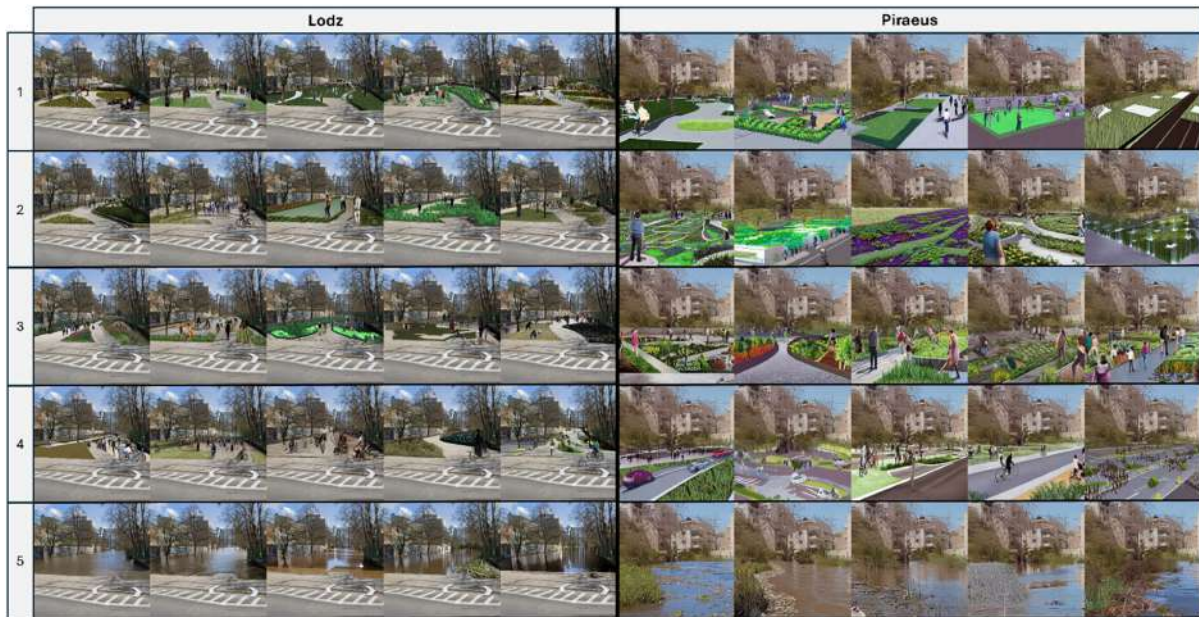


FIGURE 8. AI-generated scenarios for Lodz and Piraeus (demonstration using different scenarios).

- 1) Generate innovative design concepts for a pocket park. The park should maximize green space, provide seating areas, and incorporate sustainable materials. Consider strategies for stormwater management, biodiversity enhancement, and community engagement. The design should be adaptable to a small, irregularly shaped lot. 4K, Photorealistic, High Resolution.
- 2) Propose an NBS to mitigate urban heat island effects. Focus on integrating greenery, gardens, and tree-lined pathways. Include details on plant species selection, irrigation systems, and maintenance strategies. Ensure the solution is cost-effective and scalable implementation. 4K, Photorealistic, High Resolution.
- 3) Design an NBS to transform the neglected urban space into a multifunctional green area. Incorporate elements, such as community gardens, rain gardens, and pedestrian pathways. 4K, Photorealistic, High Resolution.
- 4) Develop a concept for a green corridor promoting ecological connectivity. Include features, such as native plantings, bike lanes, and rest areas. Address challenges, such as crossing major roads or integrating with existing infrastructure. Emphasize the corridor's role in enhancing urban resilience and biodiversity. 4K, Photorealistic, High Resolution.
- 5) Propose an NBS to address flooding and erosion. Incorporate elements, such as mangroves, salt

marshes, and permeable pavements. Ensure the design enhances coastal resilience while providing recreational and aesthetic benefits to the community. Include strategies for community involvement and long-term maintenance. 4K, Photorealistic, High Resolution.

After careful evaluation of the results, it is observed that the descriptive text prompts have a significant impact on shaping the technical illustrations of the urban planning solutions within the generated images. By specifying critical design elements, such as green spaces, pedestrian pathways, tree-line pathways, etc., the model can generate better and more realistic solutions. However, the level of detail embedded in the text prompts ensure that the rendered images incorporate realistic components and correct architectural compositions. For instance, in the last prompt, the model generated some kind of lake or river as a natural solution to floodings. Such a solution can be logical considering that the lakes and rivers are natural waterways, thus in most cases can prevent floodings; however, from technical perspective, this prompt produced unrealistic and nonimplementable solutions.

Furthermore, the structured phrasing of the text prompts enables the AI-generated solutions to integrate scalable, cost-effective, and context-sensitive designs, striking a balance between aesthetic appeal and functional urban resilience. As a result, a

descriptive and well-defined text prompt ensures that the generated images not only function as artistic representations but also serve as preliminary technical references for urban planners and decision-makers, supporting informed and strategic planning processes.

INTERVENTION DISCUSSION

Summarizing, this work proposes a novel framework for helping the experts during the early stages of intervention planning based on image-inpainting and a voting-based system for evaluating the results. To demonstrate the methodology, four EU countries' cities were selected as distinct case studies with different problems and solution scenarios. For each case study, it is asked by the generative AI algorithm to produce five solutions based on a related description addressing the challenges of intervention planning.

For evaluating the solutions, 25 people participated in the voting process. For producing statistical correct ranking results, the voting process was secret; thus, each voter was unaware of all previously votes. Moreover, it is asked by the voters to express their opinion regarding technology and its applicability in the intervention planning domain. Thus, considering the results of the four experiments, this research observed the following advantages and limitations regarding the utilization of the image-inpainting algorithms in intervention planning

Advantages:

- › The generative algorithms can produce several images in a short amount of time, depending on the GPU capabilities. Thus, such algorithms can generate several numbers of visual examples of possible interventions.
- › The huge amount of the generated solutions can be used to help the experts at the early stages of urban planning by providing brainstorming and inspirational ideas of possible interventions addressing the challenges of this stage of urban planning.
- › Thus, the early stages of urban planning are accelerated, which reduces both time and costs of the urban planning process.
- › The proposed voting-based system for evaluation of the generated solutions can be applied to enhance the public participation in the urban planning process, thus it helps democratizing and decentralizing the process.
- › The deployment of AI-assistive technical analysis using ChatGPT 4.0 or some other alternative

provides a well-defined and quick analysis of the given input solution. These tools are open access to the general public; thus, citizens can use them the same way as the experts.

Limitations:

- › The huge number of the generated solutions creates an additional challenge, which is how to evaluate these solutions. Considering that the evaluation of an architecture composition is subjective (i.e., different people evaluate the same solution differently), this problem is increasingly complex.
- › The current AI image generation algorithms are in early stages of development; thus, they lack the efficiency of producing complete, realistic, and implementable solutions (i.e., they don't understand the architecture composition and the difference between two solutions so that they can place correctly the features in the scene).
- › The proposed voting-based system for ranking the images depends on the size of the generated solutions, which means that in a large, generated dataset, the voting process will take longer.

Considering the aforementioned advantages and limitations, it is necessary to mention that more work and experiments are needed before applying such technologies in the intervention planning domain. Surely, the evolution of both AI and computer hardware in the next years will provide the necessary background for developing advanced models capable of proposing correct and realistic interventions. Moreover, the existence of such technologies is crucial, because the architects, urban planners, and general engineers will be responsible for redesigning, strengthening, and reinforcing the urban environment against the climate change's negative effects, which threatens the human health and well-being of the citizens.

Some possible continuations of this research can be: (a) the development of generative AI algorithms trained specifically for generating architectural and urban planning ideas; (b) the experimentation with more advanced ranking algorithms for the evaluation of the generated images; and (c) the combination of these algorithms with 3-D visualizations for expanding further the conceptualization of applying generative AI algorithms in intervention planning domain (i.e., 3-D planning generation inside a simulator)

Moreover, these technologies are openly accessible and can be utilized by citizens who wish to engage in the urban planning process. Not only can these citizens participate in the voting process, but they can also employ their own prompts to generate innovative ideas. In addition, the swift and efficient technical evaluation of these ideas using advanced models, such as ChatGPT 4.0 or similar alternatives, enables citizens to assess solutions from both an emotional and a technical perspective. Consequently, the combination of open access to these technologies and their user-friendly nature fosters an environment conducive to the decentralization and democratization of urban planning processes. This is particularly beneficial during the initial stages of brainstorming and designing alternative solutions.

Finally, it is important to acknowledge that since the initial release of this application, several advanced alternative models, such as DALL-E and Midjourney, have been introduced. These models demonstrate superior performance compared to the HuggingFace Image Inpainting model utilized in this research, addressing certain quality limitations inherent to the latter. In addition, it is noteworthy that even ChatGPT-4.0's text-to-image capabilities can generate innovative concepts and realistic designs. Consequently, the ongoing advancements in these digital technologies present significant opportunities for architectural and engineering applications, positioning them as valuable assistive tools in the near future.

CONCLUSION

To conclude, this work proposes a novel framework, which utilizes a generative AI model named image-inpainting for intervention planning applications. This research indicated the advantages and current limitations of this novel idea.

The main drawback of this application is that the generated solutions cannot be implemented as they are, because they lack architectural composition, but such methods can be used efficiently as an assistive tool for the architects and urban planners during the early stages of intervention planning. In this work, this drawback was addressed by a voting-based system for evaluating the generated solutions and enhancing the public participation in the intervention planning process.

Considering both the advantages and limitations that were observed, the conclusion of this work is that generative AI technology is a powerful tool

that can be effectively used in the intervention planning domain. Further research is necessary, as the current literature is limited to the utilization of generative AI algorithm in creative/art and medical domains.

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