ISSN: 2029-7955 / eISSN: 2029-7947

VILNIUS TECH
Vilnius Gediminas Technical University

JOURNAL of ARCHITECTURE & URBANISM

2024
Volume 48
Issue 2
Pages 109–124
https://doi.org/10.3846/jau.2024.20870

INTEGRATIVE ANALYSIS OF TEXT-TO-IMAGE AI SYSTEMS IN ARCHITECTURAL DESIGN EDUCATION: PEDAGOGICAL INNOVATIONS AND CREATIVE DESIGN IMPLICATIONS

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Article History:
- received 18 February 2024
- accepted 17 September 2024

Abstract. This study explores the potential of Text-to-Image (T2I) AI systems in architectural design education, particularly during the conceptual design phase. Through a structured two-stage workshop, architecture students used T2I AI to conceptualize a public building project, focusing on the bird's eye and interior perspectives. These AI-assisted designs were subsequently refined to align with specific site conditions and programmatic requirements. The study reveals T2I AI's ability to expand creative possibilities in architectural design while highlighting its limitations and biases. The findings emphasize the necessity for a critical and informed approach when integrating AI into architectural education and practice, addressing ethical considerations. Future research directions are proposed to optimize T2I AI applications in architectural design, address inherent biases in AI systems, and enhance the discourse on AI's role in shaping the future of architectural practices.

Keywords: Text-to-Image AI, architectural design education, creative process in architecture, AI in design education.

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1. Introduction and contextualization

The field of architectural design education is undergoing a rapid transformation driven by technological advancements and recent global challenges. Tepavčević (2017) highlights the significant impact of these developments on architectural design thinking, necessitating a reconsideration of educational pedagogies in the digital era. The recent shift in education has emphasized integrating advanced tools, aligning with the findings of Duarte et al. (2012) and Berkel (2020), who explored computational methodologies in urban design, showcasing the potential of digital tools in enhancing urban planning and architectural education. Artificial intelligence, particularly generative design and text-to-image (T2I) AI systems, is gaining popularity and may transform design and construction practices.

Historically, architectural education has relied on historical and theoretical references from classical treatises and specialty magazines. However, the digital era has shifted this paradigm, with platforms like Pinterest and Instagram emerging as popular yet less rigorous sources of inspiration, as discussed by Kathuria (2017). In response, our research focuses on utilizing digital tools like Text-to-Image AI technology to enhance the sourcing of project-support references. This approach, aligning with Hajirasouli et al.'s (2023) emphasis on immersive VR in architectural teaching, marks a significant shift towards a more controlled approach in reference gathering, which is crucial in today's competitive architectural landscape. Additionally, traditional design studios, as described by Schön (2017), play a pivotal role in developing architectural skills. Schön emphasizes the 'reflective practitioner' model, where students learn through a cycle of design, critique, and iteration, a process still fundamental in today's architectural education. In line with this, recent studies by Oxman (2017) discuss the evolving role of digital tools in design studios, underscoring their potential to transform pedagogical approaches.

Our study addresses two primary inquiries: the efficacy of Text-to-Image (T2I) technology in early architectural project development and the functionality and user engagement of current tools in both academic and professional settings. This investigation aims to bridge the gap between traditional architectural references and modern digital capabilities, offering insights into their role in contemporary architectural practice.

2. Theoretical framework

Artificial Intelligence (AI) has steered a paradigm shift across various sectors, challenging traditional methodologies and introducing innovative approaches. Studies spanning healthcare, business, and marketing domains exemplify AI's transformative power (Ismail et al., 2022; Lin & Alvarez, 2020; Yadav, 2021). AI has transcended conventional boundaries in higher education, enhancing student engagement, personalizing learning experiences, and optimizing educational outcomes (Eguchi et al., 2021). This evolution reflects a broader trend in academia, where technological integration is becoming pivotal in reshaping educational paradigms.

2.1. AI's confluence with architectural design

Integrating AI into architectural design represents a significant intersection of technology and creativity. In fashion and product design, AI has already demonstrated its capacity to foster novel approaches to creative problem-solving (Zhang et al., 2022; L. Wei, 2019). The application of Text-to-Image AI (T2I AI) systems marks a significant leap in architectural design, enabling the generation of visual concepts from textual descriptions (L. Wei, 2019). This development holds considerable potential for advancing the design process, yet its full impact, especially in architectural production, needs to be fully comprehended (Enjellina et al., 2023).

2.2. Theoretical underpinnings in architectural education

Integrating digital tools has been a subject of rigorous academic inquiry in architectural education. However, the application of T2I AI introduces a novel dimension to this discourse. This tool can potentially enrich the overall architectural design process, particularly in the initial conceptual phases. Using such technologies poses challenges to more traditional pedagogical methods, necessitating a reevaluation of the theoretical foundations of architectural design education (Lim & Baboo, 2022; McManus, 2018).

2.3. Bridging the gap – AI in architectural pedagogy

Exploring the use of Text-to-Image AI (T2I AI) in architecture education encompasses a complex process that goes beyond technological aspects of pedagogy. This investigation surpasses broader themes in higher education, such as the role of technology in boosting critical thinking, creativity, and problem-solving skills. It also involves understanding how AI technologies can be integrated into existing educational organizations to improve the learning experience in architectural design and related fields. Therefore, it is relevant to critically examine the AI's role in deepening engagement with design concepts to create a more dynamic and iterative learning ecosystem. In brief, the potential for AI to reshape the architectural design studio landscape is substantial, and the involved framework to effectively integrate AI into the university curriculum to enrich the educational process is challenging (Zawacki-Richter et al., 2019; Li, 2022).

2.4. Implications for higher education

Integrating AI in architectural education has far-reaching impacts on the broader landscape of higher education. Traditional teaching methods are being challenged and extended by integrating technology and AI in higher education. This shift is not only limited to architecture but is a significant movement towards innovative approaches to learning that emphasize critical thinking, creativity, and problem-solving skills. Technology and AI have enhanced the educational experience significantly and continue to do so. The role of AI in shaping future educational strategies extends across various disciplines, offering new ways to engage students and prepare them for a rapidly evolving technological world. The challenge lies in ensuring that AI is implemented in a manner that is pedagogically sound and beneficial to the overall learning experience, preparing students for their immediate educational goals for lifelong learning and adaptation in an AI-influenced world (Chatterjee & Bhattacharjee, 2020; A. Wei, 2020).

This theoretical framework sets the stage for an in-depth exploration of T2I AI in architectural education. It underscores the need for academic research that is as robust in its technological aspects as in its pedagogical considerations. The research aims to contribute to the discourse on integrating AI in higher education, focusing on its transformative potential in the architectural design process.

3. Methodological evaluation of Text-to-Image AI systems in architectural design processes

Selecting an appropriate AI system was crucial in facilitating an effective design process within our architectural case study, particularly during the conceptual design phase. To achieve this, educators in the design studio conducted a comprehensive evaluation of various Text-to-Image AI systems, focusing on key criteria such as accuracy, processing speed, user-friendliness, and overall compatibility with architectural conceptual design requirements.

3.1. Evaluation process

We systematically compared several benchmark models of leading Text-to-Image AI systems, including DeepAI, DALL-E 2, MidJourney, Stable Diffusion with ControlNet, and PromeAI. In our methodological framework, we also considered the traditional studio-based learning models described by Salama (1995), who highlighted the importance of cognitive and social dimensions in architectural education. By integrating AI tools within this framework, we aimed to maintain the balance between technological advancements and traditional pedagogical values.

Each tool was assessed based on specific attributes essential for architectural design:

a) DALL-E 2: Known for generating highly detailed and realistic images, DALL-E 2 excelled in producing visually pleasing outcomes. However, it often provided too literal interpretations, limiting the creative stretch needed for early-stage design exploration. Its strength in detail and realism was counterbalanced by its lower scores in abstract output and creative flexibility.

b) MidJourney: This software excels at creating artistic and stylized images. While its level of abstraction aligned well with conceptual design needs, it occasionally failed to balance realism and conceptuality, a critical aspect of architectural design.

c) Stable Diffusion + ControlNet: This combination offers robust control over image generation, allowing for context-specific modifications. Despite its advanced capabilities, the complexity of setup and usage posed a barrier for seamless integration into the design studio environment, particularly for students with varying levels of technical proficiency.

d) PromeAI: Designed to generate detailed and context-aware images, PromeAI provided excellent site-specific outputs. However, its steep learning curve and the need for extensive prompt engineering made it less suitable for our educational context.

e) DeepAI: In contrast, the DeepAI API was chosen for its unique ability to generate abstract images from textual descriptions, enhancing creative flexibility. Its user-friendly interface and straightforward prompt requirements made it accessible for students, encouraging exploration and iteration. The tool's capacity to produce a range of visual styles, from abstract to more detailed, aligned well with the diverse needs of our architectural design process.

3.2. Tool comparison and selection

By comparing these tools (see Figure 1), we determined that DeepAI best met the criteria for facilitating an effective and creatively open-ended design process. This choice was based on its unique ability to generate abstract images, user-friendliness, and alignment with our educational objectives. Unlike MidJourney and PromeAI, which required extensive prompt engineering or had complex setups, DeepAI offered a balance of usability and output quality.

a) Accuracy: DeepAI's outputs were aligned closely with the textual descriptions provided, ensuring that the initial design concepts were accurately represented.

b) Processing Speed: The tool's efficiency in generating images allowed for rapid iteration and refinement, crucial for maintaining the momentum of the design process.

c) User-Friendliness: The intuitive interface of DeepAI enabled students to engage with the tool effectively, regardless of their technical proficiency levels.

d) Compatibility: The ability to produce a range of visual styles made DeepAI versatile and adaptable to various conceptual design needs.

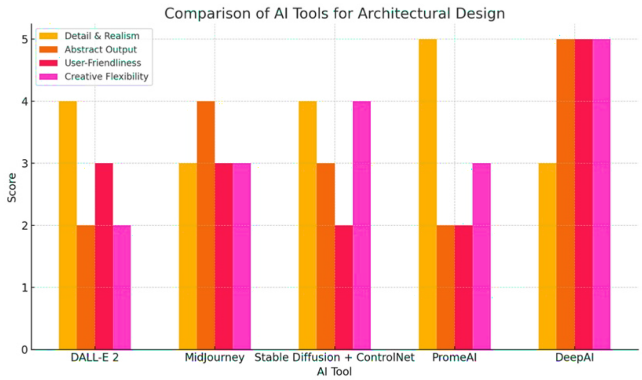

Figure 1. Comparison of AI tools for architectural design score for detail and realism, abstract output, user-friendliness, and creative flexibility

3.3. Impact on the design process

DeepAI's ability to generate abstract images from textual descriptions was a significant factor in our selection process. This feature enhances creative flexibility, allowing designers to interpret and complete the design more freely. The iterative nature of design processes in studios, as emphasized by Cuff (1991), underscores the importance of integrating new tools without disrupting the core pedagogical objectives. Our findings align with Cuff's assertion that the studio environment is crucial for developing problem-solving skills and fostering innovation. By leveraging AI tools like DeepAI, we observed an enhancement in students' creative processes, mirroring traditional studios' dynamic and iterative nature.

3.4. Practical application and references

Our preference for the DeepAI API[1] is supported by contributions from Enjellina et al. (2023), who highlight the AI Image Generator's role in broadening the design imagination through diverse visual and design alternatives. This process resonates with our study's aim to foster a rich, creative exploration in architectural design processes. Additionally, Vermisso's (2022) discussion on the opportunities and constraints of Neural Language Model-assisted processes in design creativity aligns with our exploration of T2I AI's potential in enhancing conceptual thinking. Further, Liu et al. (2022) exploration of integrating DALL-E, GPT-3, and CLIP within CAD software offers practical insights into applying Text-to-Image AI in producing reference images and materials in 3D design.

[1] The selection of the DeepAI API is deemed valid primarily for the context of the case study. Given the rapid development of AI tools, newer technologies could soon offer better or different functionalities. Thus, while the DeepAI API effectively serves current needs, this decision reflects a momentary preference that is subject to change as AI continues to evolve.

3.5. Justification for methodological choices

While our study provides insights into the use of Text-to-Image (T2I) AI systems in architectural design education, we acknowledge that our analytic methods, such as descriptive statistics and qualitative assessments, could be complemented by more advanced models. This section justifies our methodological choices and explains the constraints behind not using more advanced analytic tools.

3.6. Constraints and rationale

Our research focused on the practical applications of T2I AI systems in an educational setting, emphasizing creative and pedagogical implications. Therefore, we prioritized accessible analytic methods that are manageable for both students and educators.

Conducting the study within an academic semester posed time constraints, making training students on advanced analytic software infeasible. Given the varying technical proficiency of the architecture students, we chose user-friendly tools like Microsoft Excel to ensure broad participation without the barrier of complex software.

As a preliminary investigation, our study aimed to provide initial insights and lay the groundwork for future research. This foundational approach allows for subsequent studies to incorporate more sophisticated analytic models, building on the knowledge established here.

4. AI-enhanced architectural design: a two-stage methodology case study

The case study focused on designing a cultural and sports center that would fill the void of a large, still vacant urban area in a city center (Figure 2). The project aimed to create a new space catering to the community's diverse interests and offering a platform for cultural exchange and sports activities. The students were given a detailed brief to develop a comprehensive methodology, which would seamlessly integrate the center into the surrounding environment and enhance the overall urban landscape. The methodology was meticulously designed to blend the innovative capabilities of AI tools with traditional architectural practices, aiming to boost the creativity and precision of architectural designs.

4.1. Stage one: AI-assisted conceptualization

In the first stage, AI tools, specifically the DeepAI Text-to-Image (T2I) tool, in the selected style "Architecture Generator," were employed to generate initial conceptual designs (refer Figure 5 for details). Twenty architecture students were instructed to provide detailed text inputs describing key design elements for a public cultural and sports building. These inputs, emphasizing accuracy and intentionality, guided the AI tool to generate pertinent visual representations. Based on these descriptions, the DeepAI tool produced bird's eye and interior views of the proposed building. Students employed image editing software, particularly Adobe Photoshop, to refine these AI-generated images to modify forms, lighting, and textures, aligning the designs with tangible architectural, site implementation, and programmatic requirements. This phase was critical in transitioning from conceptual AI-generated imagery to more practical and feasible architectural solutions.

4.2. Stage two: detailed architectural development

The second stage involved students utilizing AI-generated images as foundational references for developing detailed architectural plans, sections, facades, and physical models (as seen in the conceptual diagram Figure 5). The process entailed translating the conceptual AI imagery into comprehensive architectural designs. This stage saw the creation of physical models at a scale of 1:1000 and detailed A1-size vertical panels, which provided an in-depth visual representation of the proposed designs. The plans and cross-sections, drafted at a scale of 1:500, offered insights into the building's layout, functionality, and environmental interaction. Students thus engaged in oral presentations to support these designs, articulating the rationale behind each design decision. These presentations were backed by the graphical elements and the physical model, offering a well-rounded argument for each proposed solution (Figure 3).

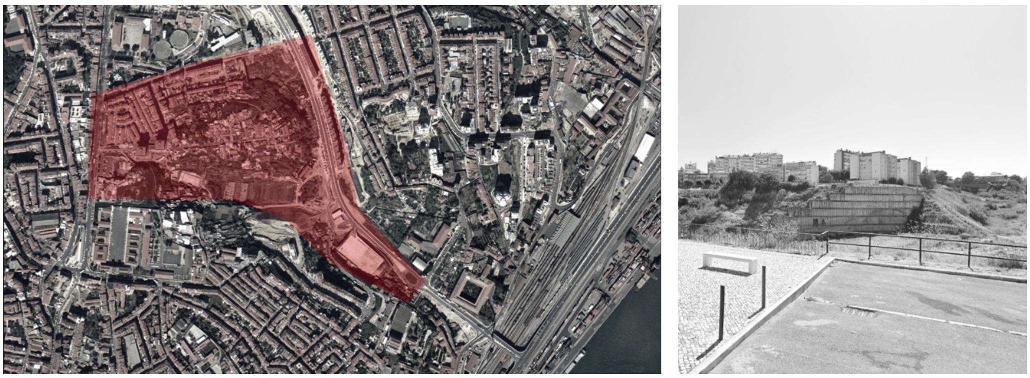

Figure 2. Plan of the intervention site (on the left). View of the location for the proposed design (on the right)

Figure 3. The photo showcases the final presentation of a student from the workshop studio. The project incorporates a very balanced blend of digital and manual outputs, which were initially produced from AI image generation during the conceptual phase, as highlighted (by the authors)

Approximately 10,000 AI images were created and examined in the study[2]. Students chose the most engaging depictions for their design scenarios. The study's outcomes were validated using a comprehensive assessment approach, including data collection, oral presentation observations, and physical analysis using 3D models and A1 panels. A Randomized Controlled Trial (RCT) group of three students was established to control confounding variables and improve the study's reliability (Shalem & De Clercq, 2022). The two-stage process showcased how AI-generated images can serve as a starting point for in-depth architectural development. The approach enhanced the architectural design by integrating AI tools with conventional design methods. This method encouraged creative exploration of design options while confirming the proposed architectural solutions' practical applicability and feasibility. The final design (ST02), as depicted in Figure 8, clearly demonstrates the integration of conceptual AI support.

4.3. Workflow overview

This case study explores how Text-to-Image (T2I) AI technology supported twenty architecture students in conceptualizing and refining their design projects. The workflow (Figure 4) integrated AI-generated visuals, iterative prompt adjustments, Photoshop enhancements, and final architectural presentations, providing a comprehensive view of the pedagogical strategy.

a) Initial Conceptualization:
- Traditional: Students sketch initial ideas by hand or use essential software tools.
- AI-Integrated: Students input text descriptions into T2I AI tools to generate initial design visuals.
- Benefit: AI provided immediate visual feedback, enabling rapid iteration and refinement of ideas.

b) Design Development:
- Traditional: Manual refinement of sketches and models, often requiring significant time and effort.
- AI-Integrated: Use AI-generated visuals as a base, refining them with additional software tools and manual adjustments.
- Benefit: Accelerated the development process by providing detailed, accurate visuals quickly.

c) Final Presentation:
- Traditional: Creation of final models and presentation materials by hand and using essential software tools.

The students' design process can be detailed as a continuous workflow integrating multiple stages, each building upon the previous to refine and enhance the final architectural concepts (Figure 4).

Each student began by submitting a text prompt to the T2I AI system describing their envisioned project based on the assignment criteria. This initial conceptualization stage allowed students to articulate their design ideas and set the foundation for further development (see the Research Conceptual Diagram for Stage One in Figure 5).

Based on feedback from professors and peers, students revised their textual prompts to refine or alter design elements. These revised prompts were then submitted to the T2I AI system, generating new images. This iterative feedback and re-prompting process was repeated several times, enabling students to refine their designs and achieve a more desirable outcome.

The AI system, utilizing DeepAI, generated initial images that visually interpreted the students' textual descriptions. These AI-generated visuals served as the first draft of their design ideas, providing a foundation for further development.

After generating these initial images, students imported the AI-generated visuals into Photoshop for further

[2] The students selected AI-generated images from a pool of around 500 options using the free version of DeepAI. This selection task was crucial as it aligned with their authorship goals. After making their selections, the students edited the images to ensure the building would fit well and look appropriate on the site.

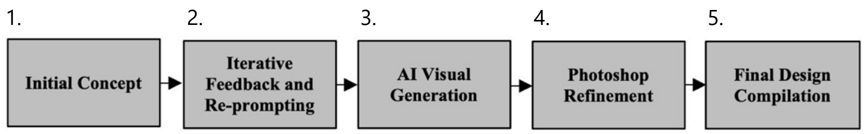

Figure 4. Workflow overview (by the authors)

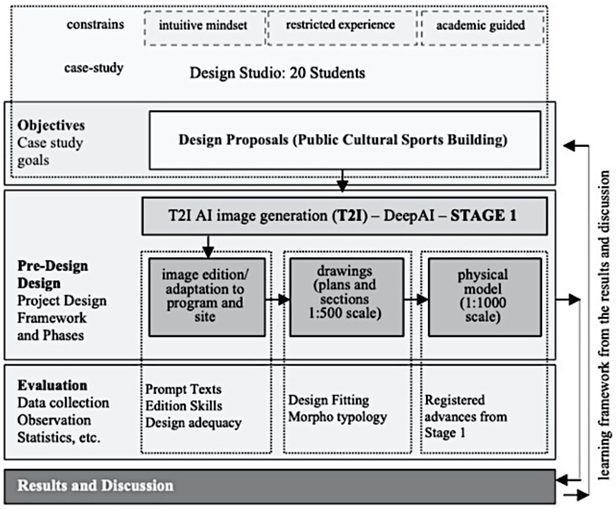

Figure 5. Research conceptual diagram for stage one (by the authors)

refinement. In this stage, adjustments included modifying colors, textures, and formal elements to align with their design vision and site-specific requirements. This refinement ensured that the building designs fit appropriately into the proposed intervention site.

Finally, the students compiled their refined designs into comprehensive presentation panels. These panels included the original AI-generated images, the Photoshop-enhanced visuals, technical drawings, schematic diagrams, and a physical model (Figure 3). This final design compilation provided a holistic view of the proposed projects, showcasing the evolution from initial conceptualization to fully realized architectural designs.

4.4. Incorporating prompt engineering in Text-to-Image AI systems

Prompt engineering is relevant to utilizing Text-to-Image (T2I) AI systems in architectural design. It involves the careful crafting of textual inputs to generate desired visual outputs. This section will elaborate on the methods and significance of prompt engineering in our study, demonstrating how iterative refinement of prompts can lead to more accurate and creative design solutions.

a) Initial Prompt Creation

Students were instructed to create initial prompts describing key project design elements. These prompts included specific architectural features, styles, and contextual elements. For example, a prompt might describe a public building with open spaces, large glass facades, and a minimalist aesthetic.

b) Iterative Refinement

After generating initial images, students engaged in an iterative process to refine their prompts. This involved analyzing the AI-generated images, identifying discrepancies or areas for improvement, and modifying the prompts accordingly. For instance, if the initial output lacked the desired level of abstraction or detail, students adjusted their descriptions to be more precise or elaborate.

c) Feedback and Adjustment

Throughout the design process, students received feedback from peers and instructors. This feedback was crucial in guiding further adjustments to the prompts. Students could better align their textual inputs with their design intentions by incorporating suggestions and addressing specific issues identified in the AI outputs.

d) Finalization

The final set of prompts represented a well-refined description that effectively communicated the students' design visions to the T2I AI system. These prompts were used to generate the final set of images, which served as the basis for detailed architectural plans and physical models.

4.5. Examples from the case study workflow and prompt engineering

Student ST01 (Figure 6):

1. Initial Prompt: "White Building, Public, Long Lines" (insufficient results).
   - AI Output: Generated images were too abstract and did not capture the intended complexity of the design.
2. Revised Prompt: "Alvaro Siza, Public Building, Top Perspective, Open Space, Sloping Land." [3]
   - AI Output: Improved results with more relevant architectural features.
3. Photoshop Enhancements: The student added accurate site topography to accommodate local features and urban elements such as hills and roads.
4. Final AI Output: This edited design features a most extended building shape with a closing perpendicular top volume towards the riverside.
   - Final design: The final design offers a more open perspective on a majestic public open space, facilitating quality communal spaces, which was well-received by tutors.

[3] Students generally preferred and decided to work with small, sectioned text prompts instead rather than fluid texts.

a) b) c)

Figure 6. This sequence illustrates the iterative design process, starting with an initial AI-generated image, refined through multiple iterations and Photoshop enhancements to align with site conditions and design intentions. STD01: a – Initial AI-generated Image; b – Intermediate Photoshop Edit; c – Final Design (physical model)

Student ST02 (Figure 7):

1. Initial Prompt: "Public Building, Cultural, Minimal, Roof" (insufficient results).
   - AI Output: Generated images were too abstract and did not capture the intended complexity of the design.
2. Revised Prompt: "Building, Cultural, Walkway, Openings, Topography, Alvaro Siza, From Above."
   - AI Output: Improved results with more relevant architectural features.
3. Photoshop Enhancements: The student added accurate site topography, including a complex network road system within the building, to accommodate local features.
4. Final AI Output: The edited design also features a most extended building volume, which embraces a football camp on the intervention site's south side.
   - Final design: The final design, which incorporates nearby sports, is more geographically inclusive and was well-received by tutors. The initial prompted image's oblique lines were further developed to create a complex roof structure, dynamizing the overall volume outline, thus creating opportunities to introduce accessible rooftops for the facility users.

Student ST03 (Figure 8):

5. Initial Prompt: "Sports Center, Cultural, Dynamic Building" (insufficient results).
   - AI Output: Generated images were too abstract and did not capture the intended complexity of the design.
6. Revised Prompt: "View-from-above, Public building, Cultural center, Sports, Diagonal, Souto de Moura."
   - AI Output: Improved results with more relevant architectural features.
7. Photoshop Enhancements: The student added more accurate site topography to accommodate the confrontation with a massive concrete wall west of the intervention site.
8. Final AI Output: The edited design features a highly complex roof structure and volumes composed of thin and long roof lines. That resulted in a compact building shape and dynamic top view that enables observation from nearby locations due to the existent topography.
   - Final design: This student did not follow the AI imagery for its conceptual design. Interestingly, in this case, the student tried to create a dissimilar design almost as a counterpoint to the AI output. So, instead of a compact building, the

Figure 7. This sequence shows the evolution of the design from the initial AI-generated image through intermediate refinements to the final design. The AI outputs provided a starting point, which was significantly enhanced to meet the project's specific requirements. STD02: Initial AI-generated Image, Intermediate Photoshop Edit, and Final Design (physical model)

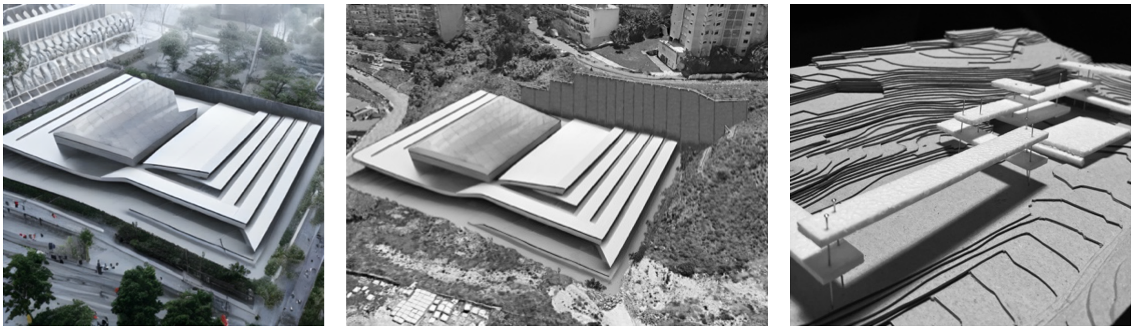

Figure 8. This sequence illustrates the iterative design process, starting with an initial AI-generated image, refined through multiple iterations and Photoshop enhancements to align with site conditions and design intentions. STD03: Initial AI-generated Image, Intermediate Photoshop Edit, and Final Design Project (physical model)

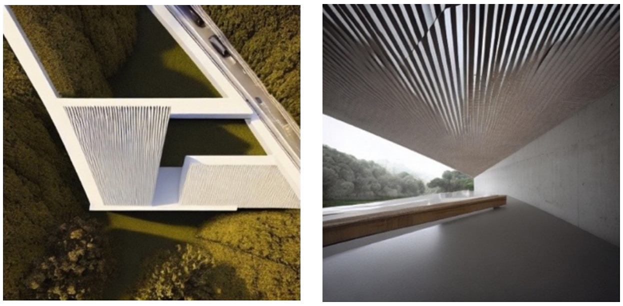

Figure 9. Selected T2I AI outputs images with exterior and "internal views" from ST01

Figure 10. Selected T2I AI outputs images with exterior and "internal views" from ST02

student developed a light and open building, as it would fluctuate all over the intervention site. The alternative design was well received by tutors, who noted the interest in having an AI image that contradicted and defied the students' creative stances.

In summary, each student's workflow included initial prompt submission, AI-generated output, iterative feedback and re-prompting, Photoshop enhancements, and final design compilation. The T2I AI seemed to facilitate faster and more creative design iterations than traditional methods, as well as more curiosity, personal interest, and discussion. Detailed visual comparisons, including side-by-side visual comparisons of initial AI outputs, intermediate edits, and final designs, highlight how AI and associated tools improved the design process regarding speed, creativity, and alignment with site conditions. In the three cases, students ST01 (Figure 6) and ST02 (Figure 7) tailored their solutions to match the AI-generated images, while student ST03 (Figure 8) opted to deviate from the initial output image and create a solution without AI support, drawing inspiration from its developed concepts instead.

Figures 9, 10, and 11 depict another design facet of the workshop: AI matching design between exterior and internal settings. The sets of T2I AI-colored images showcase

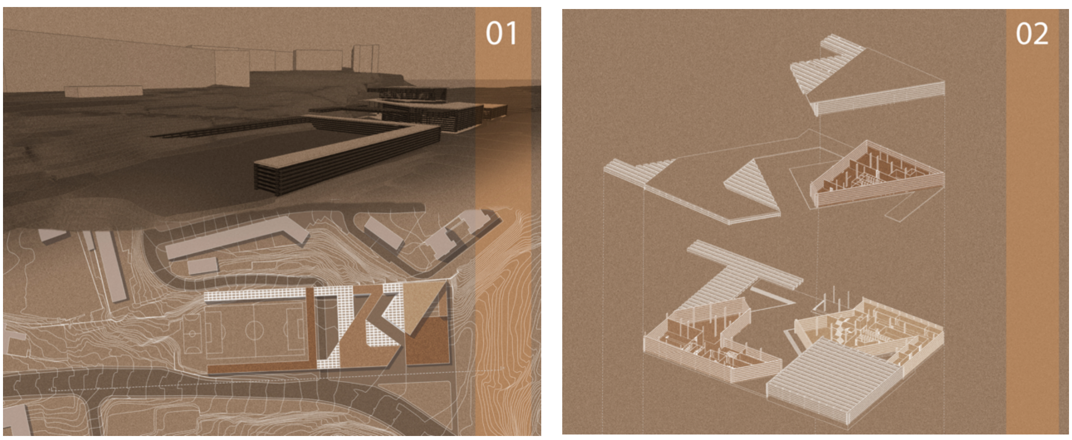

Figure 11. The design's incorporation of T2I AI image inputs is evident from the final presentation (ST01). Integrating the AI inputs demonstrates the significance of AI-powered tools in the conceptual design phase process

the designs' matching exteriors and internal views. To accomplish this, students had to hone their natural language skills to create outputs that surpassed the randomized AI results.

In ST02, the prompt text "horizontal stripes" ties together the two design morphologies, while in ST01, the prompt text "Alvaro Siza" implements a design language style that is more closely related.

Figure 11 shows a final design presentation incorporating the previous design workflow with a recurrence of AI generation for conceptual design.

5. Results

5.1. Evaluation criteria and feedback

Our research thoroughly investigated the influence of student input on the architectural design process using a methodical approach. This framework encompassed examining potential biases in text-to-image (T2I) synthesis, establishing unambiguous evaluation criteria, and advancing design skills through effective communication and feedback, as per methodologies suggested by Al-Saggaf et al. (2020). Our evaluation process involved documentation, integrating input, output data, and reports, and ensuring an objective and constructive feedback mechanism, as Harputlugil (2018) discusses.

5.2. Essential components of our assessment process

a) Defining evaluation criteria: Focused on creativity, technical proficiency, functionality, and purpose, as emphasized in the study by Li and Chen (2009), who evaluated architectural design services using the Fuzzy Analytic Hierarchy Process (AHP).
b) Objective reviews by evaluators: To ensure impartial assessments align with Albukhari's (2021) review of assessment approaches in architectural design studios.
c) Detailed documentation: Incorporating design descriptions, applied criteria, and evaluators' assessments. Cheung et al. (2002) in their multi-criteria evaluation model for selecting architectural consultants.

5.3. Text-to-Image synthesis analysis

In this research, text prompts were a key focus for understanding the nature of each image generated. Our study specifically looked at the linguistic elements of the inputs provided by students in the context of AI-generated architectural designs using text-to-image (T2I) technology. This facet entailed an in-depth examination of language components–names, adverbs, nouns, and other word categories to generate corresponding images. This analytical method was pivotal in quantifying each word type's frequency in the most effectively selected images. The analysis revealed a pronounced focus on describing the public architectural building's characteristics and features, predominantly in noun and adjective forms, such as its design, materials, and features. The notable scarcity of verbs in the text implies a lesser emphasis on the building's functions than its appearance and design. The texts' diverse words and architectural references indicated a detailed and varied discussion of the subject matter. Notably, our analysis showed nouns comprised 50% of the language used, adjectives 12.5%, adverbs 3.13%, prepositions 3.13%, and names 12.5%, with other terms accounting for 18.74% (Table 1). The analysis revealed a pronounced focus on describing the public architectural building's characteristics and features, predominantly in noun and adjective forms. This finding resonates with Frolov et al. (2021), who discussed the challenges in adversarial text-to-image synthesis, such as generating high-resolution images and developing reliable evaluation metrics correlating with human judgment. These statistics were instrumental in assessing the AI system's effectiveness in generating images accurately reflecting the students' intended design elements, resonating with the foundational work of Agnese et al. (2020), who reviewed the development in text-to-image synthesis, emphasizing the translation of human-written textual descriptions into images with semantic meaning. Their survey provided insights into key concepts crucial for our study, like generative adversarial networks (GANs) and deep convolutional encoder-decoder neural networks (DCNNs). This aspect of our research, exploring linguistic patterns' implications on design quality and bias, is supported by Liang et al. (2020) work on CPGAN. This text-to-image synthesis model focuses on parsing the content of both the input text and the synthesized image to model text-image consistency at the semantic level. This dual-purpose linguistic analysis identifies recurring textual patterns yielding superior design solutions and uncovers potential biases in AI-generated designs. If certain adjectives or names consistently lead to high-quality imagery, it may indicate a bias toward specific architectural styles or forms, necessitating acknowledgment and corrective measures.

Table 1. Word usage analysis in text inputs

Word type	Percentage
Noun	50%
Adjective	12.5%
Verb	0%
Adverb	3.13%
Preposition	3.13%
Name	12.5%
Others	18.74%

5.4. Examples of prompts and design progression

To illustrate the impact of T2I AI systems on the design process, we provide condensed examples of prompts used by students and the progression of their designs from initial AI-generated concepts to final presentations.

- Student ST01:
  Initial Prompt: "White Building, Public, Long Lines" (insufficient results).
  Revised Prompt: "Alvaro Siza, Public Building, Top Perspective, Open Space, Sloping Land."
  Final Design: Enhanced site topography and urban elements resulted in a design with a significant public open space, which was well-received by tutors.
- Student ST02:
  Initial Prompt: "Public Building, Cultural, Minimal, Roof" (insufficient results).
  Revised Prompt: "Building, Cultural, Walkway, Openings, Topography, Alvaro Siza, From Above."
  Final Design: Integrated complex road systems and a football camp, resulting in a geographically inclusive design praised by tutors.
- Student ST03:
  Initial Prompt: "Sports Center, Cultural, Dynamic Building" (insufficient results).
  Revised Prompt: "View-from-above, Public Building, Cultural Center, Sports, Diagonal, Souto de Moura."
  Final Design: Choose to counter AI output, creating a light, open building instead of a compact structure, showcasing the flexibility and creativity fostered by the AI tool.

These examples illustrate the iterative process and the role of T2I AI in enhancing creative exploration and design development. The ability to refine prompts and integrate AI-generated images with traditional design tools like Photoshop allowed students to create more sophisticated and contextually appropriate designs.

5.5. Architectural styles and features analysis

The study meticulously analyzed the textual inputs provided by the students to the T2I AI system to discern their design preferences for a proposed public facility building (Table 2). This analysis, vital for uncovering the students' conceptual leanings and inspirations, aligns with Huang et al.'s (2020) work on architect classification based on the outward appearance of the building. Their approach to identifying architectural styles through image attributes and characteristics provided a foundational methodology for our study. Regular interactions, such as meetings and workshop sessions, ensured all participants aligned with the project objectives. This collaborative approach is supported by Ashkan's (2016) phenomenological evaluation of teaching professionalism in architecture design studios, emphasizing the significance of various teaching styles and methods in shaping instructional quality and studio culture.

A breakdown of word types revealed a diverse array of architectural styles and features being envisaged by the students. This analysis illuminated the prominence of specific architectural figures and styles as sources of inspiration or reference points for their designs. For instance, the exterior design predominantly featured elements like views from above, cultural significance, and utilization of open spaces. Notably, designs reflecting Norman Foster's white buildings and Paulo Mendes da Rocha's use of concrete and greenery were recurrent themes among the students. For the interior design, themes revolving around open spaces, cultural elements, and vegetation were frequently observed.

Regarding stylistic influence, two students drew inspiration from Kengo Kuma's approach to interior design, while another student looked to Aires Mateus for guidance in material selection. Despite some thematic overlaps, each student showcased their unique vision and interpretation of the public facility building. Our data analysis indicated that Alvaro Siza was the most frequently cited architect for exterior (57%) and interior (71%) designs. Kengo Kuma was mentioned in 14% of the interior designs. In comparison, Paulo Mendes da Rocha was referenced in 14% of the exterior and 29% of the interior designs (Figure 10). This nuanced analysis is crucial in recognizing patterns that consistently yield high-quality design solutions and identifying potential biases within these solutions.

Table 2. Architectural references

Architect/place	Mention rate (exterior)	Mention rate (interior)
Siza Vieira	57%	71%
Kengo Kuma	14%	14%
Paulo Mendes da Rocha	14%	29%

5.6. Word frequency analysis

In a detailed word frequency analysis, the most recurrent word in the students' inputs was "public," appearing in 28% of the cases. In contrast, terms such as "seen from above," "culture," "water," "top perspective," "river view," and "sloping land" were among the least frequently used, each appearing only once, accounting for 4% of the total list. The diversity of names of architects or places mentioned (eleven in total) indicated the students' wide-ranging architectural inspirations. This eclectic list included various types of buildings, spaces, views, materials, nature, and other features, underscoring the breadth of considerations and influences in the students' design thinking (Table 3).

Table 3. Word frequency analysis

Word	Frequency
Public	28%
Seen from above	4%
Culture	4%
Water	4%
Top perspective	4%
River view	4%
Sloping land	4%

5.7. Study limitations

While our study provides valuable insights into using Text-to-Image (T2I) AI systems in architectural design education, it is essential to acknowledge its limitations. The research was conducted with a sample size of 20 students from a single module, which may not fully represent the diverse architectural education contexts. This limitation suggests the need for broader studies with more extensive and varied participant groups to generalize the findings more effectively. Additionally, the workshop context employed user-friendly tools to enable students to analyze contextual research data and further the learning process. The primary aim was to engage students in research analysis without necessitating a separate learning process due to the workshop schedule constraints.

Additionally, the workshop context employed user-friendly tools to enable students to analyze contextual research data and further the learning process. The primary aim was to engage students in research analysis without necessitating a separate learning process due to the workshop schedule constraints. Consequently, students and tutors predominantly utilized Microsoft Excel and its associated data analysis tools. The evaluation of design solutions relied heavily on the tutors' experience, while textual prompts were examined using Excel for data analysis. This reliance on specific tools and the tutors' subjective experience may have introduced biases that could be mitigated in future research using more advanced analytical methods.

5.8. Future research

Future research endeavors should incorporate more advanced methods, such as stylistic discourse analysis through software like Nvivo[4] or similar tools, for a more comprehensive and unbiased data analysis. These advanced methods would strengthen the reliability and depth of the research findings.

6. Discussion

6.1. Ethical implications of using AI systems in education

A set of proactive measures focused on data privacy, bias mitigation, and transparency was implemented to ensure the responsible integration of Text-to-Image AI systems into architectural design. These measures were guided by practical ethics, prioritizing beneficence and fairness and ensuring that technological advancements served the purpose while minimizing potential harm.

a) Data Privacy: One of the primary concerns was protecting student data. To address this, we implemented data privacy protocols. Personal identifiers were removed from datasets to ensure anonymity. Additionally, data was stored and accessible just for researchers. For example, student-generated design prompts and AI outputs were anonymized before analysis, and access to these datasets was restricted to users who had completed data privacy training.

b) Bias Mitigation: Recognizing the potential for AI to reflect and perpetuate existing biases, a review and adjustment protocol was set up for the AI tools used. Regular audits and model adjustments helped minimize these biases, and educational modules on AI's limitations fostered critical engagement among students. The integration of AI in architectural education also brings forth significant ethical considerations. As Bynum (2020) discusses, the ethical use of AI requires transparency, accountability, and continuous monitoring to ensure fairness and inclusivity. In our study, we emphasized these principles by implementing strict data privacy protocols and educating students about the ethical implications of AI usage.

c) Transparency: Students were provided with detailed explanations about the operational mechanisms of AI systems. Transparency was crucial as it fostered an understanding of AI's capabilities and limitations while ensuring students could critically engage with the technology. These ethical measures align with contemporary educational standards to enhance the pedagogical effectiveness of AI integration, thus enabling students to navigate and contribute to ethical discourses in future careers.

Additionally, we implemented measures to ensure that the AI tools were used transparently and responsibly. Students were educated about the potential biases inherent in AI systems and trained to evaluate AI-generated outputs critically. This educational component was crucial in fostering a critical understanding of AI technologies, ensuring students could discern and address biases in their design process.

We also emphasized the importance of maintaining the integrity of the design process by encouraging students to use AI tools as supplementary aids rather than replacements for their creative and analytical skills. This balanced approach aimed to integrate AI seamlessly into the educational framework, enhancing learning outcomes while preserving the core values of architectural education.

6.2. Case study: addressing ethical issues in practice

A key observation from our case study was how students engaged with the T2I AI system. Inputs comprising adjectives, nouns, and names of notable architects shaped the AI-generated conceptual images. This occurrence implies that students drew from established architectural styles and experiences, using these references as a foundation for their creative process. The subsequent phase involved educators guiding students to blend AI-generated concepts

[4] NVivo is a qualitative data analysis (QDA) computer software package from Lumivero (formerly QSR International). It is used across diverse fields, including social sciences such as anthropology, psychology, communication, and sociology, as well as forensics, tourism, criminology, and marketing.

with more nuanced human insights, a point underscored in work by Ploennigs and Berger (2022). Combining AI efficiency with human creativity and critical thinking emerged as a potent method for refining designs to meet specific project requirements.

Our findings suggest that while T2I AI systems enhance the visualization of ideas, they also reflect the biases and conceptual leanings inherent in the input texts. This reality underscores the importance of critical engagement with AI outputs. The student's initial designs, influenced by the AI's interpretations of their inputs, were further individualized through editing and adaptation, illustrating the transformative journey from AI-generated prompts to unique architectural designs. However, integrating T2I AI into architectural education has particular challenges. One of the critical concerns is the ethical use of AI technology, particularly in educational settings where openness and transparency are crucial.

Additionally, while T2I AI systems can mimic certain aspects of human thought, they inherently need more creative intuition and adaptability of the human mind. These systems are bounded by their programming and the data they have been trained on, which can limit their utility in more complex or innovative design tasks. Considering professors and tutors of educational courses, this setting requires a deeper understanding of how T2I AI systems function and their strengths and limitations. So, educators need to acknowledge these tools to understand them and know how to operate these systems. This learning process implies a proactive approach towards technological education, ensuring educators can proficiently guide their students using these advanced tools.

6.3. Design process insights and feedback

Our findings revealed vital insights for refining the design process and providing constructive feedback. Some students reported discrepancies between their textual inputs and the AI-generated results. For example, a typographical error in one student's input ("Slop" instead of "Slope") led to an AI-generated image that did not accurately reflect the intended design concept. This incident highlights the need for precision in textual inputs to T2I AI systems. Furthermore, some students encountered challenges adapting AI-generated images to fit specific site conditions, emphasizing the need for creative adaptability in the design process. Tutors observed that the ability to interpret and modify AI-generated images was a crucial aspect of the creative development process, shifting the perspective of these images from conclusive designs to starting points for further exploration.

Our study also found that the edited images produced in the second stage of the design process varied more in quality than the AI-generated ones. This variation underscores students' need for advanced visual aesthetics and technological understanding skills. Additionally, the analysis indicated that partial views generated by the T2I AI system encouraged more free-form design outcomes compared to comprehensive images, which sometimes imposed constraints on the adaptability of designs to site-specific conditions.

An anticipated discovery pertains to the students' distinct planning and design methodologies. As shown in Figures 3, 4, and 5, student ST02 did not use his preferred AI image to construct his project design, whereas ST01 and ST03 did so. This trend was also observed in about 25% of the students, indicating the potential necessity for them to surpass the constraints of their initial sources of inspiration to produce more free, impactful end products.

A notable observation was that one control group (RCT) utilized Revit BIM modeling and comprehensive hand sketching as part of their design process. This approach enabled these students to achieve comparable levels of accuracy and timeliness with their peers, highlighting alternative methodologies that can complement AI-assisted design processes.

This study offers a multi-dimensional insight into integrating AI in architectural design education. It underscores the importance of precision in AI inputs, adaptability in interpreting AI outputs, and the potential of alternative methodologies.

6.4. Integrating findings with existing literature

Our findings contribute to the broader discourse on AI integration in architectural education. The enhanced creativity and efficiency observed align with the studies by Duarte et al. (2012) and van Berkel (2020), which underscore the transformative potential of digital tools in architectural design. Moreover, the ethical considerations highlighted in our study echo the concerns Chatterjee and Bhattacharjee (2020) raised regarding data privacy and bias in AI applications in education.

The iterative design process facilitated by T2I AI tools supports the findings of Hajirasouli et al. (2023) on the benefits of immersive VR in enhancing design thinking. The critical role of textual inputs in generating high-quality AI outputs, as observed in our study, parallels the insights of Agnese et al. (2020) on the significance of precise linguistic elements in text-to-image synthesis.

Furthermore, the variability in design quality during the adaptation and refinement stages highlights the ongoing need for developing advanced visual aesthetics and technological skills, reinforcing the arguments of Liu et al. (2022) about integrating AI tools in CAD workflows. By bridging traditional and AI-assisted design methods, our study provides a comprehensive framework to guide future research and practical applications in architectural education.

Future research should continue to explore these intersections, examining how emerging AI technologies can further enhance educational outcomes while addressing ethical considerations. This integrative approach will ensure that AI tools are used responsibly and effectively, fostering a new generation of architects equipped with the skills to navigate and leverage advanced technologies.

6.5. Pilot projects and longitudinal study

To further validate our study's findings and demonstrate the practical applicability of T2I AI in architectural education, we propose future pilot projects in collaboration with professional architectural firms. These projects would provide an opportunity to observe and analyze how T2I AI tools are employed in real-world scenarios, offering richer insights into their practical utility and adaptability in professional settings.

Recognizing the importance of understanding the enduring effects of T2I AI integration in architectural education, we suggest conducting a longitudinal study. This extended research would track students' progress who have used T2I AI tools in their design projects over several years, evaluating how their exposure to AI affects their design thinking and creativity.

6.6. Incorporating divergences

We assert that a more comprehensive understanding of the role of T2I AI in architectural design requires a broader range of viewpoints. Interviews and surveys involving seasoned architects, industry experts, and technologists would provide diverse perspectives on integrating AI into architectural practice. This approach will bring practical insights from the field and help identify emerging trends and potential challenges professionals face in adopting AI technologies.

7. Limitations and future research

7.1. Limitations

One limitation of this study is the relatively small sample size, consisting of 20 students from a single architectural design module. This constraint limits the generalizability of the findings across different educational contexts and architectural schools. Future research would aim to include a more extensive and more diverse sample to validate and extend the insights gained from this study. Additionally, expanding the scope to include different architectural programs and institutions would provide a more comprehensive understanding of the impact and potential of T2I AI systems in architectural education.

7.2. Future research

Our study has paved the way for intricate and in-depth research trajectories that extend the exploration of text-to-image (T2I) artificial intelligence (AI) in architectural design education. These trajectories weave together theoretical and practical elements from our initial findings, offering a diverse yet interconnected roadmap for future scholarly inquiry.

The rapid evolution of T2I AI systems necessitates ongoing evaluation and refinement of these tools. Future research should be dedicated to rigorously assessing the latest AI innovations, particularly their capacity for interpreting and rendering complex architectural concepts and seamlessly integrating with diverse design methodologies. This pursuit will build upon the preliminary findings of Dehouche and Dehouche (2023), aiming to elucidate emerging AI tools' operational efficiency and creative potential in architectural contexts.

Parallel to technological exploration, there is an imperative need to develop robust ethical frameworks for AI utilization in architectural education. This aspect of research, drawing inspiration from the perspectives provided by Vimpari et al. (2023), will delve into formulating guidelines that ensure responsible and transparent AI practices. Such guidelines will be crucial in maintaining the integrity of design processes while harnessing AI's capabilities.

Cross-disciplinary applications of T2I AI, encompassing fields such as environmental sustainability and urban development, present another productive ground for research. Building upon the creative applications observed in our current study, this approach offers a more holistic and integrative view of architectural solutions, blending AI with various domains of knowledge and practice.

Conducting longitudinal studies is essential to understanding the enduring impact of AI integration in architectural education. These studies will provide insights into how continuous exposure to AI influences design thinking, creativity, and the development of architectural skills over an extended period. This endeavor will offer a comprehensive view of the transformative effects of AI in architectural education, expanding beyond the initial observations of our study.

Furthermore, the diverse range of T2I AI tools available today calls for comparative analyses to determine their suitability for specific architectural tasks. This research is vital for educators and practitioners in making informed decisions about which AI tools best align with their design needs and objectives, echoing the considerations highlighted in the work of Ruiz et al. (2022).

Transitioning from educational settings to professional practice is crucial to investigate how T2I AI tools are integrated into real-world architectural projects. This line of inquiry will bridge the gap between theoretical knowledge and practical application, providing valuable insights that complement the educational focus of our study and demonstrating the practical viability of AI tools in professional architectural contexts.

Delving deeper into technological integration within architectural education presents a significant opportunity for expansion and innovation. Tailoring educational modules to include advanced technology, particularly in architecture, can cater to a wide range of learning preferences and skill levels. This strategy extends the influential role that advanced technology plays in streamlining the architectural design process, aiming to enrich the overall learning experience by infusing state-of-the-art tech advancements.

Embracing a worldwide perspective is critical in future investigations concerning the application and reception of advanced text-to-image technology in diverse cultural settings. Research that spans the global architectural landscape promises to yield a richer, more varied understanding of the application and perception of these technological tools in varying cultural and geographical contexts.

Future inquiries are poised to traverse the dynamic and ever-changing territory of technological application in architectural design and education. This exploratory path is set to provide a thorough and practical analysis of how this technology is progressively defining the contours of architectural practices and educational methodologies. This comprehensive approach will not only enhance our understanding of technology's role in current architectural frameworks but also open doors to its potential impact on future developments in the field.

7.3. Pilot studies and longitudinal research

To validate our findings further and explore the practical applicability of T2I AI in architectural education, we propose conducting pilot projects in collaboration with professional architectural firms. These projects will provide opportunities to observe how T2I AI tools are utilized in real-world scenarios, offering richer insights into their utility and adaptability in professional settings.

Additionally, longitudinal studies tracking students' progress who have used T2I AI tools in their design projects over several years will be crucial. These studies will evaluate how continuous exposure to AI influences design thinking, creativity, and the development of architectural skills. By monitoring these impacts over an extended period, we can gain a comprehensive understanding of the long-term benefits and challenges associated with AI integration in architectural education.

Future research should incorporate a global perspective and examine how advanced text-to-image technology is applied and perceived in different cultural contexts. This broader approach will provide a more diverse understanding of AI's role in architectural education worldwide.

8. Conclusions

This study has provided a comprehensive exploration of the potential of Text-to-Image (T2I) AI systems in the context of architectural design education, highlighting both the transformative possibilities and the nuanced complexities of AI integration. Our research delved deep into the process of AI-generated design conceptualization, revealing how the precise use of language in T2I AI systems significantly influences the quality and creativity of architectural designs. The outcomes demonstrate that T2I AI accelerates the design process and opens up new avenues for creative exploration, primarily when students draw inspiration from renowned architects and styles.

A key finding of our study is the importance of accurate and thoughtful textual inputs in generating successful project designs. The study illuminated how specific adjectives, nouns, and architectural references in students' inputs led to varied design solutions, showcasing the effectiveness of T2I AI in reflecting the design process's intended meaning and conceptual approaches. This insight aligns with the broader trend of AI's transformative role in enhancing design efficiency and quality and identifying consistent design solutions and potential biases.

Furthermore, our study emphasizes the need for a balanced approach in architectural education that integrates T2I AI technology with traditional design methodologies. The variability in design quality during the adaptation and refinement stages underscores the ongoing need for skill development in technological proficiency and creative interpretation among architecture students. Our study also underscores the value of alternative techniques like Revit BIM modeling and manual sketching as complementary tools in AI-influenced design workflows.

Additionally, the research highlights the ethical implications of using AI systems in educational contexts. Data privacy, bias mitigation, and transparency were critical considerations in our study, ensuring that integrating AI tools was both responsible and beneficial to the student's learning experience. These ethical considerations are crucial in maintaining the integrity of the design process while leveraging AI's capabilities.

As AI technology progresses, it is crucial to recognize that our findings and insights reflect the present scenario and may evolve. The knowledge gained from this research contributes to the expansive dialogue surrounding architectural education, establishing a foundation for continued research and exploration. This study represents a crucial step in deepening our understanding and implementation of AI in architectural design and education.

Ultimately, this research offers substantial insights for educators, learners, and professionals in architecture. It underscores the significance of integrating AI into the design process to augment creative expression and operational efficiency while acknowledging its constraints and endorsing a holistic approach to education. As we navigate the changing landscape of AI in architectural design and education, fostering an environment that encourages analytical thought and creative investigation becomes vital. This approach will ensure that technological progress positively influences and amplifies the architectural design process, preparing students for a future where AI plays an integral role in creative industries.

As we continue to explore the integration of AI in architectural education, it is crucial to adopt a comprehensive approach that includes continuous feedback and adaptation. Future research should focus on longitudinal studies to assess the long-term impact of AI tools on students' learning outcomes, as suggested by Purcell and Gero (1998), who emphasize the importance of evaluating educational interventions over extended periods. Through these efforts, we can better understand and optimize the role of AI in shaping the future of architectural education and practice.

Acknowledgements

We thank the design students from the Lisbon School of Architecture for their creativity, dedication, and hands-on designs that provided a solid basis for our research. Their enthusiasm and diligent work ethic greatly enhanced the scope of our discoveries.

Ethical approval

This study used architectural design projects created by students. Appropriate measures were taken to ensure privacy and confidentiality, including removing personal identifiers. Ethical considerations were also considered when using AI and analytics tools to avoid potential biases and provide unbiased analysis. Overall, the research complied with ethical standards for using human-derived data and AI in academic research.

Funding

This research was supported by the Fundação para a Ciência e a Tecnologia (FCT – Foundation for Science and Technology), Lisbon, Portugal, under the FCT-Tenure program through the co-financed contract CEECINST/00112/2018/CP1530/CT0014 awarded to Nuno Montenegro.

Availability of data and materials

The study's primary data and visual representations are available in the article. The corresponding author can request supplemental materials to support the research's transparency and replicability.

Competing interests

The authors report that there are no competing interests to declare.

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