AI as Active Agent for Creative Exploration in Design Pedagogy: An AI design methodology for conceptual design in an educational context

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Keywords: Artificial Intelligence, Architectural Design, Social Media Data, Game Engines, Pedagogy.

1. Introduction

Artificial Intelligence excels at solving problems with clear answers, processing data, and performing repetitive tasks, freeing up time for architects to work on more open questions that require creativity. With today's abundance of Data and Artificial Intelligence (AI) algorithms, AEC practitioners can effectively encode, organize, and generate spectral and spatial information based on the data itself. However, it is still challenging to integrate such technologies in design workflows as an active tool for creativity and exploration. In the famous Eames Design Diagram (Neuhart & Eames, 1997), Charles Eames postulated that design processes could only be successful when they identify the overlapping needs of the designer, the client, and *"the concerns of society as a whole."* While the interplay between the first two stakeholders is well-researched and documented, the third has remained an abstract concept that relies on the designer's interpretation of the gestalt. Christopher Alexander's (1964) Notes on the Synthesis of Form could be considered an attempt to grapple with and reconcile the complexities of design methodology with a mathematical and computational basis, but also responding to the larger notion of "program" beyond the brief settled on between the designer and client. Ultimately, Alexander concludes that his was an attempt *"to show that there is a deep and important underlying structural correspondence between the pattern of a problem and the process of designing a physical form."* These patterns (datasets) are complex and varied and rely on the designer's experience, judgment, and foresight on an individual basis to orchestrate and materialize as built form. With big data from social media, we can now aggregate and analyze datasets that provide insight into the concerns and opinions of the broader public at scales previously unfeasible. Within the AEC industry, AI is often used to optimize and automate procedural, repetitive, and deterministic tasks. These tasks do not have a strong affinity with design exercises intentionally characterized for transcending optimization, in which qualitative and quantitative aspects co-exist (Lawson, 1990), and are often just as much about asking the right questions as opposed to answering them. In response to the former, this article takes a particular stance by considering an iterative collaboration between humans and machines within a design studio to test how AI algorithms and data analysis can fit within an architectural design exercise that investigates the relationship to placemaking in a natural landscape through a range of small-scale projects.

2. Methods and data

One of the main concern regarding AI in architectural design is, *"Can a machine or an algorithm truly originate something of its own?"* The latter often relates to the concept of *"Lovelace's Objection,"* enforced by Alan Turing, which calls into question if a machine is limited to merely being able to act or assess indistinguishably from a human; Turing argues that the machine can merely originate that which we as humans know how to order it to (Franceschelli & Musolesi, 2021). Such a question is one of the fundamental questions that pertain to architecture, as one might question whether an AI algorithm can act as a seed for inspiration and creativity within a design process. While there are examples of AI being used to develop conceptual designs, they are implemented within a fixed viewpoint and tasked with a specific aspect instead of a holistic overview of the entire design, such as to develop and determine an adequate overall shape or footprint for the building program (Castro Pena et al., 2021), automatically generate a floor plan (Chaillou, 2020), or generated images of facades (Ali et al., 2021). Hence, in this article, we will divert towards a different avenue that uses AI as an explorative tool for creativity and not an optimization tool for productivity. With such motivation, this article presents a fourfold methodology to implement AI and visualization tools in a design studio. The AI algorithms implemented in this work have been coded using built-in functions within the software Wolfram Mathematica (https://www.wolfram.com/mathematica/, accessed March 2022). The algorithms, software, and data sources used in the methodology are described in Table 1, which also displays which part of the methodology they have been used. In the following paragraphs, we will describe each method/module in more detail. From the four modules, we will concentrate on the explanation of Methods 2.1 and 2.2, as both use AI-powered tools and different data modalities. Methods 2.3 and 2.4 will have a less in-depth analysis as the authors have explored both in additional articles that will be cited in each section and other relevant publications about the subject.

2.1. Identification of User Needs and Context (images and text data from social media)

By the end of 2022, it is estimated that there will be 3.96 billion social network users worldwide (Yu et al. 2020). This is more than half the number of people living on the planet. One of the most significant opportunities offered by such data is the potential to understand, follow or analyze a specific topic from a third-person view, where the topic is not rooted in a specific place or time but can be viewed from various geographic locations and in different time ranges (Pandey & Purohit, 2018). Hence, the main objective of this module was to capture a concept through time and space from a third-person view or even more accurately, a collective societal viewpoint. The students' first task was to create a list of concepts that resonated with their design intentions for their projects. This was followed by an analysis of social media posts that were linked to the site, either from hashtags or geolocations, to create a new list of concepts based on the needs of the users. By joining the two lists, each student created a combination of keywords close to their initial design intent and user needs. These keywords were used to collect social media posts via an automated Twitter crawler without a geolocation constraint, collecting over 5000 social media posts per student from 2010 to 2021. Each search was different because each keyword combination was different. The students then initiated a process of automatically encoding the image data from the posts using AI feature extraction algorithms in four ways: RGB analysis (Chang et al., 1996), Edge Detection (Nadernejad et al., 2008), Fourier transform (Nussbaumer, 1981), and automatic object detection (Huang et al., 2018). Each student selected a method to encode their data that was meaningful to their interest. After having the data numerically encoded, they input it into an unsupervised clustering algorithm called a Self-Organizing Map (SOM) to represent the data in a reduced 2-dimensional space (Kohonen, 1990). As the posts are multimodal, they can be visualized using either their image (Figure 1) or text representation (Figure 2); thus, this reduced 2-dimensional grid can be used to understand the type of images that each student collected with the selected keyword combination.

Consequently, they can select a group of cells (that

	Type	*Data*	*Method/Module*
Algorithm	Automatic Twitter crawler	Images and text	2.1
	Automatic Object Identification	Images	2.1
	Fourier Transform	Images	2.1
	RGB analysis and Edge analysis	Images	2.1
	Self Organizing Maps (SOM)	Images	2.1 and 2.2
Software	Cloud Compare	Point clouds	2.3
	Rhino	Point clouds/Mesh	2.3
	Unity	Point Clouds	2.4

Table. 1 Description of Types of Algorithms and Software used in each method within the methodology

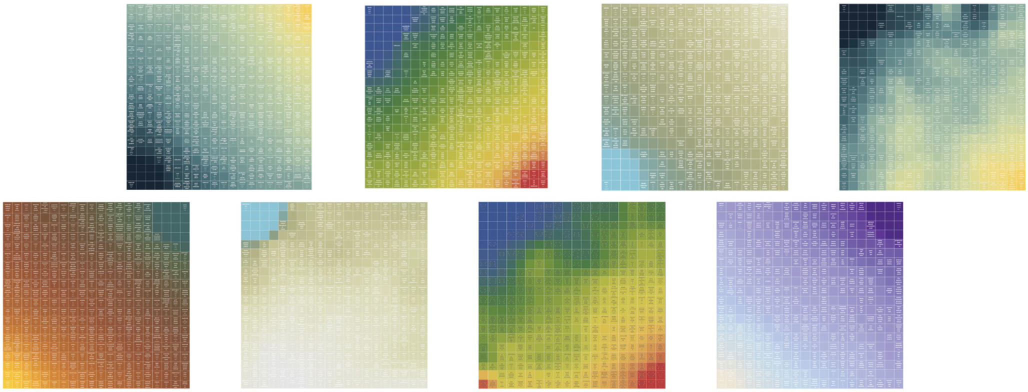

Fig. 1 A compilation of SOM grids (output from an unsupervised clustering algorithm) organized by the text data from the collected social media posts

by themselves are groups of similar data points) to continue with the exploration that aims at creating an atmospheric understanding of such initial concepts for the design intervention (Figure 3). After selecting a group of images, the students started a collage process to create an atmospheric image (Figure 4). These images attempt to capture their intention through concepts they want to engage in their designs. Through this exploration, the students had a different understanding of the site that included a collective viewpoint characterized by the users and their activities. This approach goes beyond the typical site analysis that relies on limited site visits and mappings related to the site's physical infrastructure and targeted interviews.

2.2. Storytelling and Branding (text data from digital books)

A common approach to writing a design brief is to find inspiration from books or articles dealing with theoretical or philosophical quests to describe concepts that are considered essential for the experience of the proposed design solution. However, one is often constrained to a particular line of thought by exploring known books or literary samples previously read. Nowadays, with AI, we can expand our sight and access various libraries that offer multiple lines of thought. In this module, the students used *ALICE* (https://ask.alice-ch3n81.net), an AI power search engine that relates authors by the

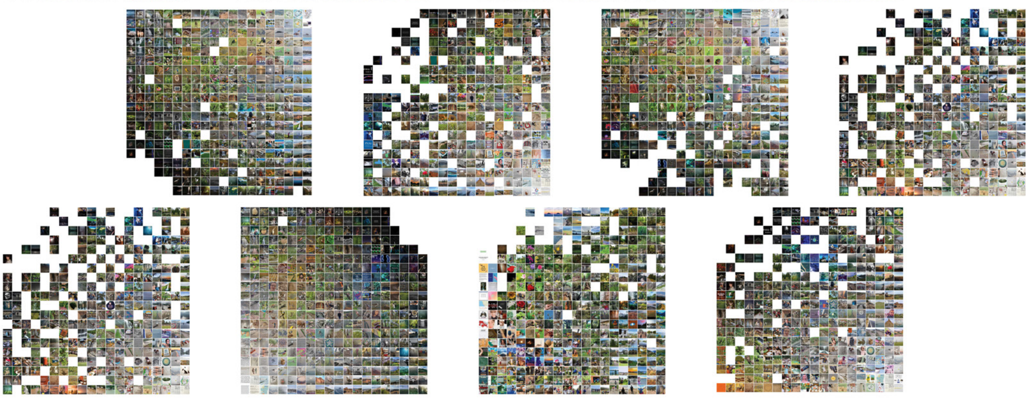

Fig. 2 A compilation of SOM grids (output from an unsupervised clustering algorithm) organized by the image data from the collected social media posts

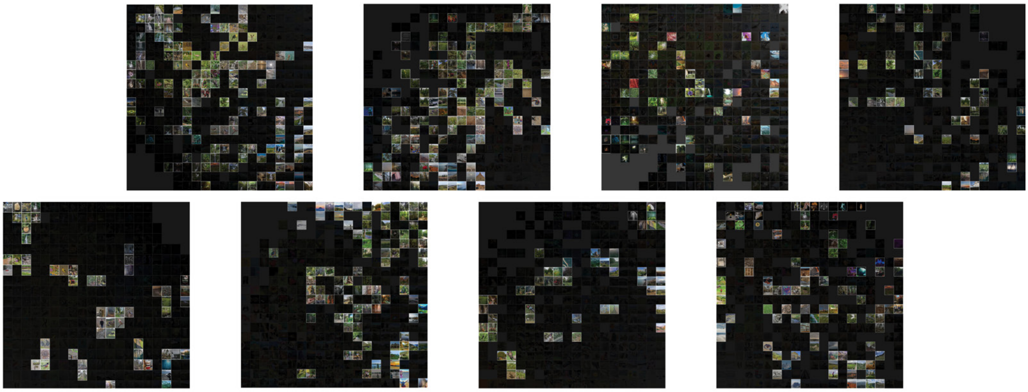

Fig. 3 A compilation of SOM grids (output from an unsupervised clustering algorithm) organized by the image data from the collected social media post, overlaid with the selection by each student of images that resonated with their initial concepts

similarity of their text, and displayed paragraphs that included specific keywords to describe a concept. *ALICE* runs Natural Language Processing algorithms to create word embedding from books and then uses an unsupervised clustering algorithm, Self Organizing Maps, to organize clusters of similar texts. The writing exercise focused on using *ALICE* (AI tool) to power creativity and expand the students' horizons when approaching a project. In this module, the students were encouraged to write a design brief including the keywords developed in Method 2.1 to describe their possible intervention. Then they used those same keywords to find quotes from a curated library of books to enrich their text, approaching the task as a collaborative writing exercise. After querying *ALICE* with their keywords, students are exposed to a list of paragraphs that describe a particular line of thought and can be used to brand their existing design brief description. The final text included at least five quotes meaningfully joined in each text description from the design brief. By using an AI-powered tool to write a design brief, the standard individualistic approach is challenged as now the discussion is enriched by various authors addressing the same topic to articulate a comprehensive description of the design intensions. The following paragraph is an excerpt from such a design brief:

Fig. 4 Atmospheric images, a collage of selected images organized by SOM, these images capture the design intentions that students wanted to materialize in their designs

"One might say architectural construct is a natural site for symbiosis to form, but only a certain type of symbiosis can occur as architecture and nature maintain differential relationships between their components.3 An example of such symbiosis we are all familiar with is the garden, a form of land which extends beyond maximizing biotechnology.4 It is the point of convergence between the artificial and the natural, an opportunity to create deeper meaning. These botanical gardens bring together a living canvas—sensuous, olfactory, and colorful—of all the botanical resources relevant to a larger picture.5 This relationship will undoubtedly present an opportunity for life to grow as a byproduct.6 There are many interpretations of what life is; what constitutes something being alive? But "living", in architecture, means an adequate relation to life.7 Furthermore, a relationship to other things; the forest becomes a piece of art. As all art, life is volatile; Le Corbusier realized that although 'nature presents itself to us as a chaos ... the spirit which animates nature is a spirit of order'.8 Imagine, in short, buildings as life support systems in harmony with energy flows, human souls and other living things.9 Organisms are attracted to what sustains life and repulsed by what threatens life.10 The intervention seeks to become alive, to evolve into a living part of the whole, by acting as a sort of blank canvas, for the site to turn into a work of art. "

2.3. Curating and Modeling Space (from point cloud data from terrestrial laser scanning)

Designers commonly use sophisticated computer-based software to represent three-dimensional projects (e.g., Rhino, Revit, Blender, Cinema 4D, etc.); one of the most significant problems with these software visualizations (traditional polygon surface modeling) is to simulate landscape at high fidelity. This task is often problematic due to the significant consumption of time and resources (de Souza et al., 2015). In order to overcome this limitation, we propose to work with point cloud models. Point cloud models are the digital representation of a set of tridimensional coordinates that precisely measure the environment; they can be interpreted as GPS coordinates having X as latitude, Y as longitude, and Z as the elevation. We used two methods to collect a point cloud model of the site. First, students used their mobile phones (with a LIDAR laser scanner) to gather point cloud data of specific places. Second, we used terrestrial LIDAR laser scanning to capture the overall site. All the point cloud models were registered using Cloud Compare (Girardeau-Montaut, 2016) and were further segmented according to each student's preference and design intentions. By exploring the site through the point cloud model, students experienced a new exposure to the site as the porosity of the point clouds make it possible to see through walls and surfaces, accessing "hidden" spaces and unique views otherwise not accessible. The idea of a 3D model that represents the exact reality gives the flexibility and confidence to initiate the design process knowing that all changes will be placed and performed in the exact place. (Nir & Capeluto, 2005, Saldana Ochoa 2017). By working with a point cloud model, students can index the site differently; they could explore areas on the site that were physically inaccessible and work directly on a precise representation of the site. This precise model was transformed into a mesh in Rhino and used to CNC fabricate a physical site model. (Figure 5)

Fig. 5 Images of the physical model of the site, on the left we can observe the layers defined by the CNC machine on the right is the final result by smoothing the surface, the trees are located exactly where the existing trees are in the site.

2.4. Materialization of the Project (through 3D printing and game engines)

Both the entertainment industry and the design community benefit from game engines and animation walkthroughs to help emphasize and explore design projects (Anifowose et al., 2020). Although AEC practitioners do not directly design interactive and entertainment games, many have pushed the boundaries of virtual reality to express spatial ideas (Hoon & Michale, 2003). Therefore, for this module,

Fig. 6 A Sample of work from the students point cloud models visualized in Unity

after segmenting their point cloud model in Cloud Compare, students moved to Rhino to concretize their design intentions, keeping in mind both the atmospheric images and the design brief as sources of inspiration for their projects. They then imported their design solutions into Cloud Compare to transform the 3D models (traditional polygonal surface modeling) into point cloud models while retaining the materials assigned from Rhino. After this process, the students imported the point cloud models into Unity. Once in Unity, they used Point Cloud Viewer and Tools to visualize the point cloud models. A critical aspect of this module was deciding which objects should be enhanced. As a technical limitation, currently Unity can only display 20 million points per scene. Therefore, the students needed to decide which elements to populate with more points, prioritizing objects that comprise more significant gestures of the proposal, and with fewer points those that are distant or less essential. This selective amplification of site and design elements reintroduces the “agency of mapping” and its active role in design (Corner, 1999). They used cameras and agents to create an interactive visualization of their project similar to (Leitão, 2020; Barsan et al., 2020); Figure 6 shows an example of four projects visualized in such a manner. Finally, the models were 3D printed using the Rhino digital model to obtain a physical model situated within the CNC-milled site model for their final presentation.

3. Discussion

Through this methodology, we showcased a series of modules that explored methods for implementing AI into an architectural education plan. The results of this research showed that the inclusion of AI and big data analysis can augment various creative abilities allowing designers to focus on questions that require human creativity rather than machine productivity. Recognizing that certain phases of the design process require iterative and recursive thinking, the application of AI can be used to augment and expose potentials and possibilities within phases that require parallel and lateral associative thinking akin to brainstorming. These methods are applied to the early phases of schematic design and territories in which the broad use of AI techniques as generative, interpretive tools to convey conceptual and narrative ideas that are in the early stages of exploration. The impact can be seen particularly in the first and third steps of the design process outlined above because they take particular care to the “concerns of society as a whole” (Eames & Eames, 1996) as they consider a collective input – social media data and excerpts from books. With the proposed validation process, we were able to identify which design abilities were augmented in each of the steps in the proposed design workflow.

a) Identification of User Needs and Context vs. Site Analysis; the ability to grasp a concept through time (10 years) and space (various geographical locations) by exploring its representation on thousands of social media images to help render an atmospheric understanding of the users' needs and defining the project brief.

b) Storytelling and Branding vs. Design Brief; the ability to co-author a richer narrative by exploring thousands of architectural theory and philosophy quotes timely, organized around the desired concepts defined in method 2.1.

c) Curating and Modeling Space vs. Design Response; the ability to iterate various design solutions at a greater speed than before, due to working on a site through its precise digital representation of point cloud models.

d) Materialization of the Project vs. Design Representation; the ability to represent complex geometry through 3D printed and virtual reality.

4. Conclusion

In a cursory attempt to summarize a more conventional model of site analysis, we may refer to the classic 1981 book Site Analysis: Diagramming information for architectural design by Edward T. White (White, 1983). Traditional site analysis tends to focus on overt geographical features such as figure/ground relationships, vehicular and pedestrian circulation, sightlines, topography, etc., such that even the diagrammatic representation of these sometimes-transient factors tend to be deterministic and static, with clear delineation of edges, boundaries, and trajectories. White acknowledges that "site is never inert but is an ongoing set of very active networks that are intertwined in complex relationships" (White, 1983), yet its presentation and pursuit of graphical and narrative clarity through abstraction oftentimes results in oversimplification. While useful as a design tool for understanding and synthesis, these diagrams fall short of describing the nuances and complexities of a site. They can perform well when conditions are more binary such as urban contexts; however, when faced with natural landscapes with gradations the single level of abstraction and resolution tends to be overly reductive. While certainly representational techniques have progressed substantially since White's treatise, the fundamental conceptual approach to site analysis has largely stayed the same in academia and practice, almost 40 years later. This issue is particularly exacerbated when designing for the public realm, in which the user base and constituents are ill-defined, leading to a scenario in which one of the primary stakeholders is essentially in absentia. While the client is technically the government in these cases, the user's true public sentiment may not be faithfully represented. If we understand the expansive definition of site analysis (Module 2.1 atmospheric image) to encompass society and culture, and program as a reflection of such concerns (Module 2.2 writing the design brief), the tools employed in the research begin to construct a way of symbolically synthesizing both data and the designer's intent, as a powerful methodology for design exploration. The SOM used in Module 2.1 served to capture "the concerns of society as a whole" across a specific geospatial territory as well as over time, and provide a broader holistic view of public sentiment. The point cloud model (Module 2.3), due its dual nature of accuracy and abstraction, served as a living site the students could refer, analyze, and in cases edit or recompose to work with a design narrative, and ultimately leverage to materialize their projects in both physical and virtually experiential formats (Module 2.4).

Let us return to Christopher Alexander's (1964) assertion that the designer never fully understands context in its entirety, but in "pieces" that are major aspects of the problem to be focused on. As "there are limits on the number of distinct concepts which we can manipulate cognitively at any one time," one must prioritize and sift through the fields of information to uncover and expose poignant design issues. Characterized as "good fit" between form and context, architects strive for the tension that such a relationship creates, understanding that the context in which it exists is constantly in flux (Arango, Dubberly, 2018). The capability of AI-assisted workflows that enable the uncovering and symbolic representation of such patterns is at the core of Modules 2.1 and 2.2 described above. While prior algorithmic processes strive to be deterministic in search of a unitary response, the current generation of AI models are capable of dealing with non-deterministic problems when given enough data, finding the irregularities that lead to form as the "diagram of forces," characterized by D'Arcy Wentworth Thompson (1956) in On Growth and Form. Acknowledging that there is still much work to do in order to ensure ethical and bias-free interpretation of data, it is important that students take responsibility for the data we use, recognizing that AI is not solely to optimize processes but can be used to power creativity. Having “limitations in tools is not new to architectural processes,” but a thorough understanding of such processes is critical such that the tools are not misused or misunderstood (Meekings, Schnabel, 2016). The design framework presented in this article joins already well-explored tools in design practices (point clouds, 3D printing, and game engines) with newly-explored tools (AI algorithms) that resulted in design solutions articulated through such a joint effort with artificial and human intelligence. “In its largest sense, design signifies not only the vague, intangible, or ambiguous, but also the strive to capture the elusive.” (Terzidis, 2006), and this new generation of AI tools are well-equipped to help uncover the elusive and augment the perception of human designers.

Acknowledgements

The authors thank the students in the course for their openness to trying new tools all the time.

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