Navigating Design Space in the Creative Process

Integrating machine learning for structured exploration avoiding design fixation

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Architectural design problems are inherently ill-defined, requiring iterative exploration of complex design spaces. A key challenge at this stage is design fixation, where early exposure to specific ideas limits creativity. While Machine Learning (ML) is increasingly used in design, many tools generate fixed solutions, which may reinforce fixation. This research proposes a novel ML-supported method that structures design space using typologically clustered schemas. By abstracting detailed architectural plans through segmentation and image translation models, the approach offers nonprescriptive visual stimuli to support creativity. A mixed-methods study, combining theoretical analysis, a workshop experiment, and digital prototype development, demonstrated that schema-based exploration fosters quicker iteration, broader exploration, and reduced fixation. The findings suggest that ML can serve as a structuring aid for design ideation, enhancing human-machine collaboration without constraining creative agency.

Keywords: *Design Fixation, Machine Learning, Building Typology, Design Space, Co-creation.*

INTRODUCTION

At the early design stage, architects must process large amounts of information, ranging from precedent cases and contextual data to functional requirements, while formulating initial concepts. However, effectively navigating this information and identifying key insights can be challenging. Additionally, early-stage design proposals across architecture, engineering, and other design disciplines, are frequently revised in response to ongoing feedback, necessitating rapid exploration of alternatives under time constraints. As noted by Jansson and Smith (1991), the conceptual phase plays a disproportionately influential role in shaping the overall outcome relative to the time spent on it. While computational tools exist to support the design process, many primarily focus on generating (Park et al., 2024; Su et al., 2024; Vissers-Similon and Dounas, 2024) or sorting (Fuchkina et al., 2018) fixed solutions. This risks shifting the architect's role from creator to curator, limiting their ability to explore freely. While such fixed-solution generation proves beneficial in later design stages, where quantifiable parameters like heating efficiency or green space coverage can be optimized (Wang, Chen, and Yan, 2024), it is less applicable in the early stages, where qualitative factors such as aesthetics, contextual fit, and cultural identity play a crucial role. Since these aspects cannot be reduced to numerical optimization (Dorst, 2006), applying Machine Learning (ML) in early design stages risks reinforcing design fixation, presenting seemingly final solutions that fail to address the complexity of the design problem (Dortheimer et al., 2023, Sebestyen et al., 2024).

This study hypothesizes that ML can be leveraged differently, not to generate rigid solutions but to facilitate structured exploration, helping architects navigate design spaces without constraining creativity.

Methodology and Expected Outcomes

Rather than relying on ML to produce predefined solutions, this research explores how ML can structure and cluster design data, enabling architects to investigate diverse possibilities freely. By organizing the design space by typologically clustered schemas, this approach provides abstract stimuli that support ideation while avoiding fixation (Figure 1).

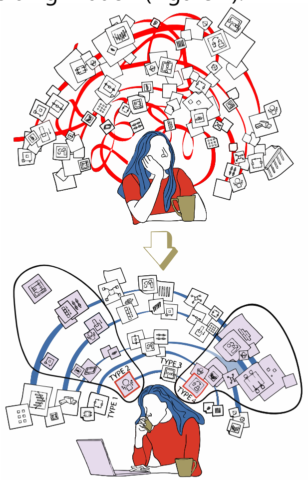


Figure 1 Conceptual representation of the expected outcome: transforming an unstructured design space into a typology-clustered framework, improving navigation, and presenting abstract schemas as creativity support

The study evaluates this method through a two-phase prototyping process. First, a paper prototype was tested in a workshop with master-level architecture students to assess the conceptual framework. Then, a digital prototype was developed and tested through interviews with architecture professionals, examining its effectiveness in real-world design scenarios.

Beyond validating this methodology, the research seeks to bridge the gap between traditional design practices and intelligent tools. By aligning digital augmentation with the iterative nature of architectural design, this study aims to ensure that ML-driven approaches enhance rather than constrain creativity.

BACKGROUND

The emergence of design methodology in architecture responded to the growing complexity of design problems. Alexander (1964) highlighted the difficulty of managing vast, unstructured information and advocated for structured strategies. Among these, iteration plays a key role, helping designers navigate uncertainties by breaking complex problems into manageable parts and repeatedly refining solutions (Wang, 2022).

References and the Risk of Fixation

To help with solving complex design problems, architects often collect design references, precedents that inform and inspire. This practice helps them map and navigate the design space by drawing on pre-existing knowledge (Gero and Milovanovic, 2022). However, Gero (1990) distinguishes three ways references can function:

- Archetypes: Idealized examples that define a category.
- Stereotypes: Repetitive copies limiting originality.
- Prototypes: Flexible starting points supporting creative expansion.

When references are copied without reflection, they become stereotypes and may trigger design fixation, a cognitive bias that restricts exploration and leads to missed opportunities (Belém, dos Santos and Leitão, 2019). This risk is heightened in the early design stage, where time constraints often prevent critical analysis of references.

Stereotypes to Prototypes: Role of Abstraction

Whether a reference fosters creativity or fixation depends on how it is presented (Figure 2). Research on design cognition (Jansson and Smith, 1991; Vasconcelos and Crilly, 2016) shows:

- Detailed, solution-like stimuli (e.g., photographs, detailed plans) increase fixation, prompting designers to adopt existing features unconsciously (Cardoso and Badke-Schaub, 2011).
- Abstract stimuli (e.g., schemas, and conceptual diagrams) reduce fixation and stimulate associative and analytical thinking (Gabora, 2010).

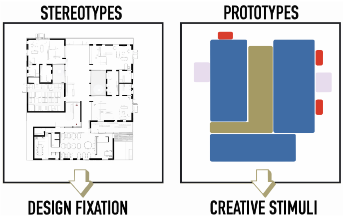


Figure 2
A detailed plan (left) fosters fixation as a stereotype, whereas an abstract schema (right) fosters creativity as a prototype

Thus, abstracting references into schemas transforms them into prototypes (open-ended frameworks that support creative exploration).

Building Typologies as Abstract Schemas in Design Exploration

In architectural design, schemas serve as cognitive structures that organize and generate spatial ideas. Kant described schemas as mediators between perception and understanding (Hays, 1979), and typologies function similarly: providing conceptual scaffolds without dictating specific solutions. A schema distills spatial relationships and organizational logic, functioning like an architectural "alphabet" that enables variation without fixation.

By abstracting collected design cases into typological schemas, architects can structure their exploration of the design space without falling into fixation. This approach supports creative variation and accelerates iteration while leveraging established spatial patterns.

RELATED WORK

Gallo, Tuzzolino, and Fulvio (2020) found that architects viewed ML as a transformative yet underutilized technology, primarily due to its steep learning curve and concerns over unoriginal outputs. As a result, ML was largely confined to well-defined tasks. However, in the years since, advancements such as the Transformer model (Vaswani et al., 2017) and diffusion-based models (Ho et al., 2022) have reshaped this perspective by lowering the technical and computational barriers to entry and challenging the notion that ML merely replicates training data.

However, while these advancements lower technical barriers, their impact on architectural creativity remains underexplored. Existing literature agrees that intelligent tools should enhance exploration rather than produce rigid solutions, as design fixation hinders innovation (Dortheimer et al., 2023). Fixed Artificial Intelligence (AI)-generated outputs are unsuitable for early-stage design, where aspects such as aesthetic judgment, contextual appropriateness, and cultural identity remain difficult to quantify computationally. Despite the growing adoption of AI, ensuring that these tools enhance rather than constrain architectural thinking is a critical and unresolved challenge.

This aligns with co-creative AI principles, where AI augments human intuition rather than replaces it. Studies suggest intelligent tools can stimulate creativity (Kim and Maher, 2023). For instance, Agkathidis, Song, and Symeonidou (2024) demonstrated that AI-generated nondomain stimuli, such as seashell forms, boosted associative thinking, allowing architects to produce better design options. However, while these studies focus on associative creativity, there is a lack of research on intelligent tools' role in enhancing analytical creativity, a crucial aspect of design reasoning (Gabora, 2010).

Research Gap

Existing intelligent tools primarily function as generative systems, producing outputs for selection rather than encouraging architects' creative thinking. While prior studies explore how intelligent tools can stimulate creativity through external stimuli, little research addresses how such tools can support the analytical side of creativity by organizing design knowledge in alignment with architectural methodology.

This study seeks to fill this gap by developing an intelligent tool that operates within the domain-specific design space, aligning with architectural theory and practice. Instead of disrupting existing workflows, it aims to enhance them through computational structuring, allowing architects to navigate design space more systematically without prescribing solutions. By bridging established design methodologies with digitally augmented approaches, the research ensures that intelligent tools support, rather than limit, the open-ended nature of architectural design.

A NON-PRESCRIPTIVE APPROACH TO ML IN ARCHITECTURE

The integration of ML into architectural design should navigate a critical challenge: ensuring that it supports creative exploration rather than constraining it. While ML has demonstrated strong capabilities in generating solutions, such approaches often risk reinforcing design fixation: a phenomenon where early exposure to fixed outputs limits the range of ideas explored. This is particularly problematic in early-stage design, where architects must iterate through loosely defined, evolving concepts rather than optimize predefined parameters.

To bridge this gap, the proposed approach repositions ML not as a generative tool but as an organizational framework: one that structures typological knowledge and supports design space exploration without imposing solutions. Instead of producing static outputs for selection, ML is leveraged to:

- Extract abstract schemas from a large dataset of architectural references, reducing detailed designs into high-level typological structures.
- Cluster schemas to reveal latent spatial and formal patterns, helping architects navigate design space systematically.
- Provide non-prescriptive visual stimuli that serve as creative prompts rather than definitive templates.
- Process and structure vast datasets to visualize potential design trajectories, supporting iterative workflows rather than narrowing options.

By structuring the design space in a way that remains open-ended, ML can enhance architects' ability to explore, iterate, and refine concepts without restricting creativity. To test this hypothesis, the study employs a two-stage research design:

- Paper Prototype Experiment – a low-tech prototype was used in a workshop setting with master's level architecture students, assessing whether structured typological schemas improve design ideation compared to traditional reference-based approaches.
- Digital ML-Driven Prototype – insights from the initial phase inform the development of a computational tool, which was tested through expert interviews to evaluate its effectiveness in real-world design workflows.

By framing ML as a structuring mechanism rather than a fixed-output generator, this approach ensures alignment with architectural design's inherently iterative and exploratory nature. The study thus bridges the gap between design methodologies and computational augmentation, demonstrating how ML can enhance rather than disrupt the creative process.

Figure 3
Materials provided to the participants of the experiment. On the right side – three schemas, on the left side, nine plans. Participants were either working with three schemas or with nine plans

METHODOLOGY. TESTING THE HYPOTHESIS

To initially assess whether abstract schemas representing building typology provide greater benefits for design space exploration than detailed design references, an experiment was conducted before developing an ML-based tool. The experiment employed a paper prototype simulating a simplified digital prototype. The primary objective was to compare two approaches:

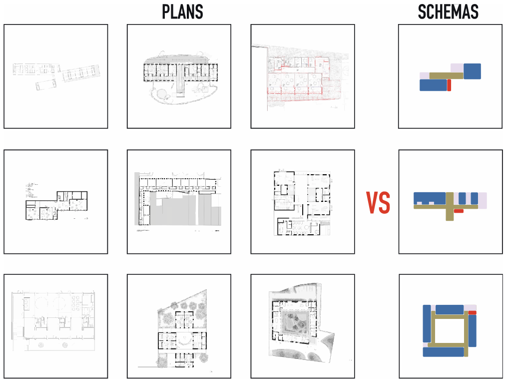
- Traditional Approach: Participants used highly detailed, unstructured design references (architectural plans of the buildings).
- Schema-Based Approach: Participants worked with visual representations of structured design spaces in the form of abstract schemas, serving as creative stimuli.

Data Collection. A qualitative and interpretive approach was used to assess participants' design behavior and perceptions. Screen recordings of participants' screens were used to create visual timelines of design actions and option sequences. These helped interpret individual decision-making patterns, serving as a cross-reference against participants' responses in surveys and interviews. Additional video footage of participants interacting with the materials (detailed plans or schemas) was reviewed to identify behavioral tendencies, such as engagement style and reference use, and to assess consistency with self-reported experiences.

Pre- and post-experiment semi-structured interviews and questionnaires captured subjective insights on clarity, conceptual support, and creativity. Responses were compared across the two experimental approaches (traditional vs. schema-based) to assess perceived design freedom and iteration strategies.

Paper Prototype Design

Two sets of materials were prepared (Figure 3):



- Traditional Approach: Participants received nine detailed plans of buildings, sourced from an architectural database (Divisare, 2024).
- Schema-Based Approach: The same building plans were analyzed by authors, categorized by typology, and transformed into schemas. These were further grouped into typological clusters, with each cluster represented by a single abstract schema. Resulting in three schemas given to participants.

Schema Transformation Process. Four categories were labeled on the building plans based on typological analysis:

- High-Hierarchy Spaces – Primary functional areas (e.g., classrooms, living rooms).
- Low-Hierarchy Spaces – Supporting areas (e.g., storage, bathrooms, utility rooms).
- Vertical Connections – Structural elements enabling movement between floors (e.g., stairs, elevators).
- Horizontal Connections – Circulation spaces within the same level (e.g., corridors)

These identified categories facilitated clustering by typological similarities (e.g., central vs. perimeter circulation).

Experiment Design

To minimize bias, each participant worked with both design support approaches (schemas and plans) and across two building typologies: kindergartens and private houses, accounting for differences in spatial complexity. Each session lasted 60 minutes, following precedents in related studies (Jansson and Smith, 1991; Cardoso and Badke-Schaub, 2011), and began with a task to generate as many design options as possible using the provided materials. (Figure 4).

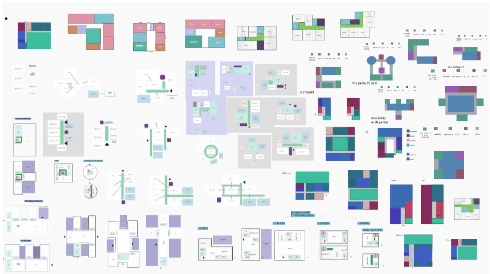


Figure 4
Design options produced by participants

Participants then completed a clustering task, grouping their concepts by perceived typologies, followed by generating new options that moved beyond those categories. After this, they received the alternate material type (schemas or plans, as half started with plans and another half with schemas) and repeated the design task. Sessions concluded with interviews and questionnaires. Each approach was tested six times (equaling the number of participants), totaling 12 trials.

Results with the Paper Prototype

The experiment aimed to interpret how schema-based design support influenced early-stage architectural ideation. Findings emerged through triangulation of interviews, questionnaires, and observations from screen and video recordings:

- Schemas facilitated concept-focused ideation. Participants reported developing options faster and focusing on broader spatial relationships rather than details.
- Participants perceived clearer starting points with schemas. Interview responses and observed behavior suggested that the structured typological cues helped them establish design logic more quickly.
- Participants explored a wider design space. In interviews, participants described feeling freer to diverge and explore unfamiliar configurations. (Figure 5).

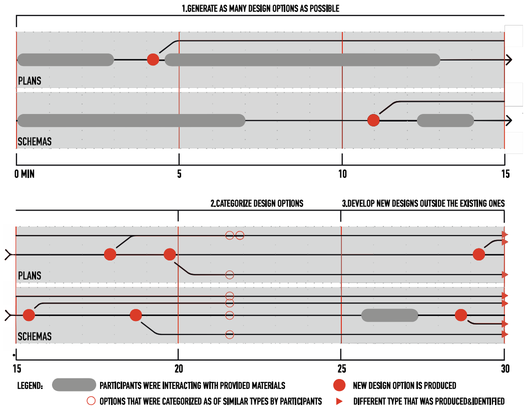


Figure 5
Workshop results example on a timeline – one of the participants working with plans and one working with schemas

Digital Prototype Development

Based on the promising paper prototype results, a digital prototype was developed. The objective was to automate the schematization and clustering of building typologies through ML-driven processes (Figure 6).

Turning plans into schemas. Two methods were tested to convert architectural plans into schemas:

- Image-to-Image Translation (generative adversarial network (GAN)-based). Using a fine-tuned pix2pix (Isola et al., 2016) model.
- Image Segmentation (Computer Vision-based). An adaptation of a Roboflow (2024) 3.0 model fine-tuned on the custom dataset with a COCOn-seg checkpoint for instance segmentation.

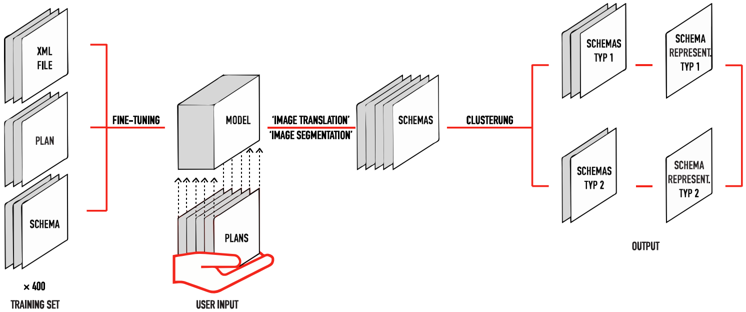


Figure 6
Digital prototype development with training, input, and output

Data Collection & Model Training. The dataset consisted out of 400 architectural plans sourced from the Divisare (2024) database. For preprocessing, plans were manually segmented into high-hierarchy, low-hierarchy, and circulation spaces (applying the same principle as for the paper prototype) using the CVAT (2024) tool for image labeling. For training Image Translation model was fine-tuned for 200 epochs, the Image Segmentation model was fine-tuned for 170 epochs. For evaluation models were tested on unseen architectural plans.

Comparative Results. The Image Segmentation fine-tuned model performed better overall, with accurate segmentation at a >50% confidence threshold (Figure 7). The Image Translation method showed variability but demonstrated promising results in recognizing spatial categories. For the final prototype, the Image Segmentation method was utilized.

Figure 7
Results of fine-tuned Image Segmentation Model

The fine-tuned image segmentation model is publicly available, allowing architects to upload references (recommended minimum: 20) to generate schemas and later cluster them into common types.

Image Clustering. To systematically cluster architectural schemas, a feature-based approach was developed, ensuring that classification criteria aligned with architectural principles rather than generic image clustering techniques. A set of predefined features was established to distinguish spatial and typological characteristics of architectural schemas. Each schema was analyzed based on:

- Overall composition: Single volume vs. multiple interconnected volumes.
- Circulation patterns: Presence and arrangement of horizontal and vertical connections.
- Connectivity: Degree of spatial fragmentation: centralized, distributed, or linear.

Feature Extraction Process. Identified attributes formed the basis for meaningful clustering. A Large Language Model (OpenAI, 2025) was used to analyze schemas and extract qualitative features based on predefined spatial characteristics.

Unsupervised Clustering. A combination of clustering techniques, including K-Means, Agglomerative Clustering, and HDBSCAN was applied (Scikit-learn, 2024) with automatic hyperparameter optimization for each method. To enhance accuracy, an ensemble approach integrated results from individual algorithms, improving the model's ability to distinguish distinct spatial typologies, such as centralized layouts, distributed functions, and fragmented configurations.

Validation & Refinement. Two master level students independently reviewed the clustering results to ensure alignment with recognizable typologies (Figure 8). This validation process confirmed that the generated clusters represented meaningful spatial distinctions.

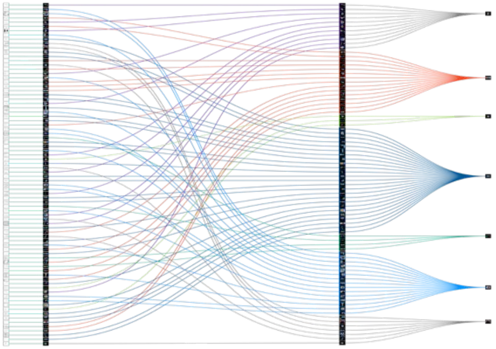


Figure 8
Visual representation of the results of clustering

RESULTS EVALUATION

The study employed a mixed-method approach to evaluate the impact of structured schemas on design exploration across two phases.

Summary of Paper Prototype Findings. As reported earlier, the paper-based experiment showed that schema-based prompts supported clearer conceptual framing, improved iteration speed, and fostered exploration beyond familiar solutions. These effects were consistently supported across screen timelines, clustering behavior, and interview responses.

Digital Prototype Evaluation. Since the core concept had already been validated through the paper prototype, the digital prototype evaluation focused on usability and integration into real-world architectural practice. The tool was tested through interviews with three practicing architects. Participants observed that the tool mirrors a manual process they already engage in when time permits, namely, analyzing references by typology and abstracting them into conceptual schemas. This suggests that the tool enhances rather than disrupts existing workflows. Specifically, it supports faster iteration and more structured exploration, addressing common limitations of early-stage design such as time constraints and unstructured precedent analysis. Architects also expressed interest in features such as the ability to modify schemas and trace them back to original plans, capabilities that will be considered in future development.

Interpretation of Findings

The results indicate that abstract schemas effectively structure the design space, reducing fixation while encouraging creative exploration. User testing with both paper and digital prototypes demonstrated the viability of this approach for early-stage workflows.

- Building typology provides an inherent logic for structuring design spaces and improving navigation and exploration.
- Schemas serve as cognitive scaffolds, allowing designers to focus on spatial relationships rather than being constrained by precedent-based thinking.
- Machine learning models can successfully abstract architectural plans into structured schemas, aiding systematic exploration.

Limitations

The controlled nature of the study and its relatively small sample size may limit generalizability. Further research should test the approach across diverse architectural contexts. While this study utilized building typologies, other methods for representing spatial relationships may also be effective. Future iterations should improve user-friendliness based on feedback from final interviews with architects.

Future Research

The next steps can include refining design space navigation to enhance usability and accessibility, as well as experimenting with alternative abstract analytical stimuli beyond building typologies. Furthermore, investigating the evolving role of architects in human-machine collaboration, focusing on how intelligent tools can augment creativity rather than replace intuition, has to be explored further in research.

OUTCOME

This study contributes to architectural design by bridging traditional methodologies with emerging technologies. The schema-based approach introduces a structured yet flexible way to explore design space, encouraging creativity while mitigating fixation. Its key contributions include enabling faster iteration and systematic navigation of alternatives, demonstrating that machine learning can abstract plans into schemas capturing essential typological traits, and offering cognitive support by providing architects with intuitive, structured frameworks for early-stage decision-making. By integrating typology-based schemas into workflows, architects can access established design patterns, improving the efficiency and breadth of spatial exploration.

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