A Case Study of the Development of a Sensitivity-Based Interactive House Design Assistance System Using Generative AI. *

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ABSTRACT

This paper presents a case study on the development of an interactive residential design support system that uses generative AI to integrate residents' sensitivities and requirements into the design process. The system automatically extracts sensory information from texts and images and generate design elements. This method facilitates effective dialogue between designers and residents, enabling the creation of design proposals that are both specific and aligned with individual preferences. Prototype evaluations confirm the system's ability to generate detailed design elements and demonstrate the utility of its sensory analysis. The paper concludes with a discussion of current limitations and outlines future directions in enhancing design diversity and integrating external data for comprehensive design management.

CCS CONCEPTS

Human-centered computing → Human computer interaction (HCI) → Interactive systems and tools

KEYWORDS

House Design, Assistance System, Generative AI

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1 Introduction

The lifestyles and family structures are rapidly diversifying, leading to increasingly complex demands on housing needs. To adapt to these changes, housing designers must respond to a wide range of requests while maintaining high quality. Additionally, moving away from a short-term "scrap and build" approach, creating housing that residents can live in with affection for a long time is expected to contribute to solving societal issues by building a stock of homes. However, the requests for increasingly complex demands may increase the burden on housing designers. Thus, there is a need for new design methods that flexibly meet diverse needs while reducing the burden on housing designers.

To address this, we developed a system that enables designers to analyze design constraints and interactively generate house designs using generative AI.

This paper details the concept of the system, specific technical challenges, the evaluation methods, and results of the prototype system. The outcomes of this study not only contribute to the streamlining of the housing design process but also demonstrate the potentials of generative AI in the design field.

2 Related Work

In the process of house design, numerous studies have been conducted to identify residents' needs and propose design elements. Traditionally, methods based on the experience and heuristics of designers have been the mainstream for extracting sensitivities and needs, using affective engineering [7].
With AI advancements, data-driven design support systems have gained attention. AI systems propose furniture arrangements [8], and methods exist to translate preferences into design briefs [2]. Integrating generative models with BIM for design support has also been suggested [3] [4]. A study that supports the generation of preliminary interior design concepts is presented by RoomDreaming [9], which leverages generative AI to streamline design exploration processes. With the development of large language models (LLM), there have been increasing attempts to incorporate LLM into the design process [5][6].
In this study, we developed a system that uses generative AI to automatically identify resident sensitivities and output them as concrete design elements.

3 Challenges in Housing Design

The design of individual residences requires considering a diverse range of factors such as the family structure, lifestyle, and sensitivities of the inhabitants. Moreover, there is a demand to provide society with stock of houses that can be lived in for a long time with affection. The main challenges are outlined below.

3.1 Difficulty in Identifying Sensitivities

To design a home that residents can cherish for years, it is crucial to identify and incorporate their unique preferences. Therefore, the authors introduce a design methodology based on the design philosophy of "life knit design." Life knit design is a philosophy that aims to realize a home that harmonizes with life and can be cherished over time by "weaving" the individual sensitivities, their life with family, and their memories into the design. However, since sensitivities are subjective and ambiguous, this task becomes challenging for less experienced designers. Depending on the content, it may impact discrepancies in imagery, design quality, and project progress.

3.2 Difficulty in Understanding Resident Needs

The needs of modern residents have grown more complex and diverse than before due to the diversification of lifestyles and family structures. It is not easy for residential designers to grasp these varied demands and propose homes with long-lasting affection. This challenge is particularly pronounced when residents cannot clearly articulate their expectations. This issue often impacts the design proposal due to a lack of dialogue skills in the initial design phase.

3.3 Difficulty in Reflecting Site Information

To provide comfortable homes that residents can live in with affection for a long time, it is essential to understand site information such as light entry and wind flow. However, this requires extensive knowledge and experience, making it difficult for less experienced designers to make informed judgments.

4 Details of the Proposed System

In this study, we developed an interactive housing design support system using generative AI. This system contains three elements: (1) Sensitivity Identification, which analyzes inputs to determine resident preferences, (2) Design Element Generation, which creates spatial and furniture proposals, and (3) a Dialogue Interface for interactive refinements.
This chapter provides a detailed explanation of key algorithms and specific functions.

4.1 Organizing Inputs

The input data was determined through interviews with designers. The input information for the system is outlined below:
Resident Attributes: The number of residents, gender, and age.
Resident Information: Detailed attribute information about the residents, including their hobbies, values, and residential needs.
Resident-Selected Images: Images presented by the system that the resident selected as preferred, with comments on those.
Resident-Brought Images: Images chosen from internet or pictures taken by the resident with comments.
Site Condition Information: Information about the site conditions of the location, along with field and aerial photographs.
Resident Preferences: Information about specific people or brands the residents particularly favor.

4.2 Organizing Design Elements

The necessary elements for generating design components were organized. Additionally, whether each element addresses the challenges mentioned in Section 3 has been indicated.
(1) Output incorporating sensitivity (addressing 3.1)
This element aims to understand the resident's sensitivity through resident-selected or resident-brought images. Based on this, furniture is searched within the database and incorporated into the design to suit the preferences.
(2) Output incorporating attachment (addressing 3.2)
The customer's needs are identified as spaces to which the customer has an attachment. This space with attachment will henceforth be referred to as the "attachment factor."
(3) Output incorporating site conditions (addressing 3.3)
The site conditions with texts, field and aerial images are reflected in the design. The system generates design elements that consider site constraints while addressing residents' requirements.

4.3 Sensitivity Identification

Figure 1 shows the flow of sensitivity identification.

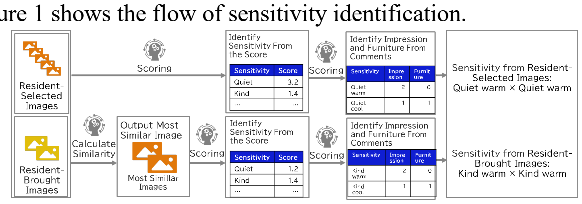

Figure 1：Flow of Sensitivity Identification.

Sensitivity information has been defined across 12 categories (6 major categories, each with 2 subcategories). A method was developed to output which sensitivity category applies based on resident-selected images and resident-brought images.

(1) Sensitivity Identification Based on Resident-Selected Images
The resident-selected images are pre-tagged with sensitivity categories and relevance scores. First, from the scores of five resident -selected images, and the major category of sensitivity with the highest total score is chosen. Next, the subcategory with the most comments is chosen.

(2) Sensitivity Identification Based on Resident-Brought Images
First, the similarity between resident-brought images and a prepared set of images is determined. Similarity is calculated by comparing the histograms of the images. Then, like the procedure in (1), sensitivities are selected from the most similar images.

4.4 Generating Design Elements

Figure 2 shows the flow of generating design elements.

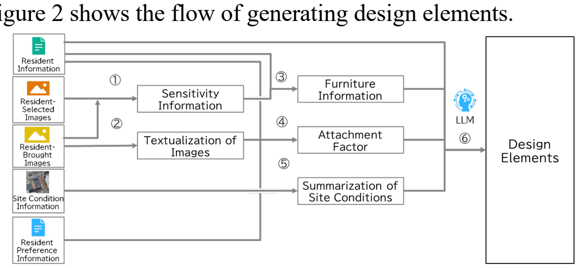

Figure 2：Flow of Generating Design Elements.

The design elements are created through the following steps:

(1) Output of sensitivity information.
Identify sensitivity using the method outlined in Section 4.3.

(2) Textualization of images.
Convert resident-brought images into text using GPT-4o.

(3) Search for furniture information based on sensitivity.
Search for furniture information using the identified sensitivity and resident information. The search utilizes bge-m3 [1] by pre-vectorizing the furniture information and output the information by a cosine similarity with the customer information.

(4) Output of attachment factor.
Determine the attachment factor (spaces likely to hold attachment) using GPT-4o, based on sensitivity, resident preferences, and the textualized resident-brought images.

(5) Summarization of site conditions.
Use GPT-4o to perform image textualization and summarization of site condition information, including text and images.

(6) Output of design elements.
Generate design elements using GPT-4o based on the resident information, furniture information from step (2), the attachment factor from step (4), and the summarized site conditions from step (5). Table 1 shows the prompt for generating design elements.

Table 1: Prompt for Generating Design Elements

We are thinking of recommending home ideas for residents who are planning to build a new house. Based on the reference information, please select the attachment factors below, and propose a "place of residence within the living room" in about 50 words, comprehensively incorporating the contents of the selected attachment factors. If there are any site conditions, make a realistic proposal that considers these conditions. # Resident Information <Resident Information> ＊snip＊

4.6 Dialogue Interface

The dialogue interface enables housing designers to modify the generated output via chat, reflecting their specific design preferences.

The specific procedure involves inputting the design elements into the prompt along with the instruction "Please modify as follows," and then adding the content written in the chat.

4.7 Outputs

Figure 3 shows the output image of this system.

Figure 3: Output Image of This System

On the left side, we output image generation from design elements and "Lifestyle," "Design Concept," and "Interior Ambiance" by summarizing design elements with each perspective.

On the right side, the design elements outputted in section 4.5 are presented, along with the attachment factors used in their creation. Table 2 shown an Example of outputs in this system.

Table 2: Example of Outputs

Design Elements	Reading Nook that Captures the Path of the Wind In one corner of the living room, a reading space is established by a well-ventilated window. Positioned where the breeze pleasantly flows through, it creates an inviting environment with reading lights that enhance the play of shadows. This space allows for a quiet reading experience while still feeling the presence of family. Attachment Factors: "A Space to Feel the Flow of the Wind", …
Lifestyle	In the sunroom-like space of the living room, enjoy natural light while indulging in reading or spending quality time with family.
Design Concept	Ensure optimal lighting with large windows and skylights facing the east road, while evaluating soundproofing performance.
Interior Ambiance	The bright wooden flooring and simple white walls reflect soft light, creating a pleasant ambiance throughout the living room.

5 Evaluation

In this study, an evaluation was conducted using a prototype system to verify the effectiveness of the developed system. The evaluation focused on its usefulness in interactions with designers and residents. Below, we provide a detailed description of the evaluation data, evaluation subjects, and evaluation contents.

5.1 Evaluation Data

For the evaluation, seven sets of hypothetical resident data, which include text and image information as described in Section 4.1, were created. Outputs based on these resident data were assessed by individuals involved in housing design and sales. In creating the hypothetical resident data, actual design projects were used as a basis, and examples of these data are shown in Table 3.

Table 3: Example of Hypothetical Resident Data

Resident Information	- Occupation: Business owner, desires a place suitable for reading. - Hobbies: Camping, BBQ, DIY. - Values: Prefers having children study in the dining area, wants a kitchen usable by the entire family ＊snip＊
Resident Attributes	- Male, 30s - Female, 30s - Female, preschool age
Resident- Selected Images	Image 07, Image 14, Image 35, Image 38, Image 42
Resident-Brought Images	  Likes the ambiance of the lighting and the wooden feel of the flooring.
Site Condition Information	Osaka Prefecture, ZZ City, XX Ward, East side faces the road, while the South and West are close to other houses.
Resident Preferences	Tasha Tudor

5.2 Evaluation Subjects

In this study, two evaluation experiments were conducted. After refining the prompts based on the first evaluation, a second evaluation followed. In the first evaluation, 14 practitioners participated, while 15 practitioners participated in the second evaluation. They were asked to evaluate each of the seven hypothetical resident data sets via a questionnaire. The first evaluation garnered 98 responses, and the second one received 104 responses, resulting in a total of 202 evaluation responses.

5.3 Evaluation Subjects

The questionnaire required participants to evaluate the results for each data on a five-point scale: "1. Very useful", "2. Useful", "3. Neither", "4. Not useful", and "5. Not at all useful". Additionally, participants were asked to provide comments on the results.

6 Results

Table 4 shows the Result of the Evaluation.

Table 4: The Result of First and Second Evaluation.

	1. Very useful	2. Useful	3. Neither	4. Not useful	5. Not at all useful
1st	19	58	17	4	0
2nd	16	41	40	6	1
Sum	35	99	57	10	1

In the first evaluation, the combined percentage of responses for "1. Very useful" and "2. Useful" reached 78%, while in the second evaluation, the percent was 54%. The first and second evaluations generally indicated that the system was useful, but in the second evaluation, the responses of usefulness decreased. This decline is attributed to the presence of more experienced evaluators in the second evaluation, who did not find the system as useful. From these results, we concluded that the system is especially useful for less experienced personnel. Positive comments included opinions such as "the affective analysis is easy to understand," "responses are concise and easy to understand" and "the furniture proposals are specific." However, there was requests for improvement in addressing two-generation housing and requests for system integration instead of inputting via the current UI.

7 Discussion

Based on the evaluation results of the interactive housing design support system developed in this study, we discuss the system's effectiveness and prospects.

7.1 Effectiveness of This System

The evaluation results indicate that the system demonstrated a certain level of effectiveness in identifying resident needs through affective analysis and providing proposals based on those needs. In particular, the mechanism of converting subjective elements into concrete design elements was positively evaluated, enabling space creation that meets the sensory demands. Additionally, the system was highly regarded for making proposal content explicit as design elements, ensuring proposal consistency, and facilitating clear explanations to residents.

7.2 Challenges and Future Work

However, there were challenges in this system:

Enhancing Flexibility of Design Proposals: As the proposal content depends on a certain template, there may be cases where specific resident needs are not fully addressed. It is necessary to add diverse templates and expand the affective analysis model according to residents' needs.

Strengthening System Integration: There is a growing demand for seamless online management of resident information and integration with external data, enabling comprehensive design management.

8 Conclusion

This study developed and validated a generative AI-based housing design support system. Future work will focus on expanding design diversity, system integration, and UI enhancements.

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