International Journal of Engineering & Technology, 8 (1.4) (2019) 56-64

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Approach to Design Reference Management using Auto-Recognition System of Room and Design Style

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Abstract

This paper aims to propose an approach to managing interior design reference images using the automatic recognition system for room and design style. In practice, architects, designers, and other interested parties actively use web-based platforms for which design references are provided with a well-organized information structure. In particular, the photograph has the role of a primary source to support analyze, and understand architectural design. However, the current management approach consumes significant time and design expertise resources. In addition, the approach to managing and labeling filenames that are irrelevant to the image itself is inefficient and can lead to errors. Therefore, we use a deep learning mechanism and pre-trained image recognition model to retrain the model with the Korean apartment room and its design style. Using image recognition technique, it is possible to classify design images with only visual pixel data and measure the visual similarity. We developed a prototype GUI application that supports checking the result of the automatic recognition and management. In addition, the reference image data can be effectively searched and utilized through more specific search functions and both stochastic keyword-based and visual similarity-based retrieval.

Keywords: *Design reference image; Deep learning; Image recognition; Automatic classification; Interior Design*

1. Introduction

Referring to previous design cases is one of the most useful strategies for developing solutions in architecture and interior design [5, 24, 26, 28]. Design information in cases is represented in various ways such as documents, drawings, and photographs. Among these, photographs of design results are useful media to gain inspiration or ideas and communicate with clients in design processes as a reference. Therefore, an efficient management system or method of storing, retrieving, and reusing design images is needed. Architects, designers, and other interested people actively use web-based platforms in which design reference images are provided with a well-organized information structure. In these platforms, a common way of managing reference images for the interior design needs significant human resources and time. Despite being supported by database management systems or algorithms, Designers and professionals have to directly and deeply participate in image management. They have to personally tag the category with domain knowledge and iterations of classification and storage are heavy burdens on designers, can interfere with the consistency of their work and create many errors. Furthermore, regarding the reuse of data, they could only retrieve what they wanted with strings or should explore and find images from the DB themselves. This can prevent users from thoroughly finding and examining useful information; there is a growing demand for more intelligent and supportive systems.

Deep learning and convolutional neural networks have shown the successful results of image recognition and the classification of general content images [13]. In addition, the core technique also enables the fast and precise discovery of similar images like Google image search. The ultimate goal of this research is to develop an intelligent interior design reference management system that supports design tasks. The designer could sedulously and easily find primary references with stochastic keyword-based searches and visual-based searches. As basic research for the goal, this paper's objective is to develop an automatic recognition module that can classify and save according to certain categories using a deep learning-based pre-trained image recognition model (e.g. Figure 1). The target image is limited to the Korean apartment interior design and the categories include some room use and the design style of the living room. After resetting the pre-trained model, automatic recognition with stochastic results and classification is demonstrated. A prototype GUI application that supports and visualizes automatic recognition is depicted. In addition, a stochastic keyword-based and visual similarity-based retrieval function are proposed and demonstrated using the main application. The research process is as follows:

1. To finding available technology for automatic recognition, measuring visual similarity, and setting the environment.
2. To setting the criteria of target images and collecting and pre-processing the image data of room use and the design style of the living room
3. To re-train the interior image recognition model and analyzing the results of testing.
4. To demonstrate automatic image recognition with a GUI application and stochastic keyword-based and visual similarity-based retrieval, respectively.

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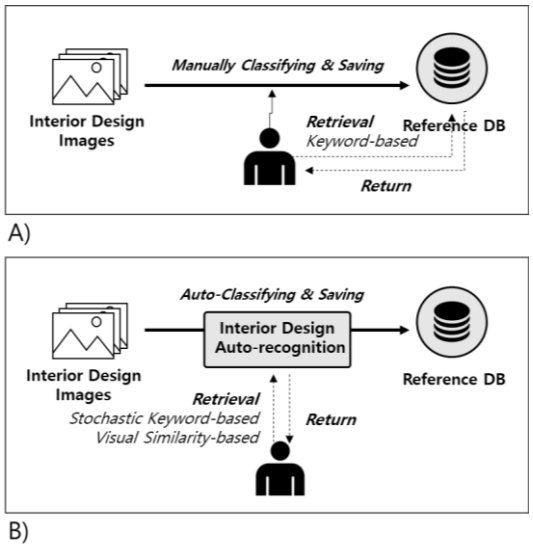


Fig. 1: The above A) is the current approach and B) is a proposed approach to managing interior reference images using deep learning-based image recognition.

2. Background

2.1 Impact of Reference Image in Design

Rittel and Webber[25] defined the problem that has characteristic of vagueness, changing requirements sometimes difficult to recognize as "wicked." In reality, professional practice throughout the design process has to face and deal with "messy, problematic situations" [27]. Cross[4], Lawson[14] explained that architects, engineers, and other designers adopt problem-solving strategies based on the generation and testing of potential solutions, unlike scientists who utilize the problem-focused strategies with well-formed problems.

One strategy developing alternative solutions for new designs is to refer to previous cases that are related to new design situations or goals [2, 3, 18, 20]. In architectural design practice, previous experience and prior design solutions are stored, retrieved, and reused [7]. However, design information in such cases is usually unstructured and represented in diverse ways such as drawings, documents, and photographs. Therefore, some researchers have suggested methods such as case-based design or precedent-based design systems to efficiently manage and support their utilization [5, 24, 26, 28, 7].

Visual representations have traditionally been used by architects in the role of primary sources to support the analysis and understand architectural design [12]. Among these representations, we focus on photographs as a design reference image. Reference images as the result of design-like façades or interior photographs are particularly helpful for getting inspiration or communicating with clients in the early design process. It is very informative and helps us understand the design.

2.2 Design Reference Image Management

Even if architecture or interior design firms commonly have their own reference digital database systems or libraries, architects, designers and other interested people actively use web-based platforms that provide design reference images with well-organized information structures (e.g. Figure 2). For example, "Houzz" is the world's most popular online platform and provides approximately 16,693,200 photos of housing and outdoor design references. In addition, interfaces to filter design images according to various features deeply related to housing design decision-making are commonly provided (e.g. Table 1). In housing design, room use and design style are basic categories. Designer, location, size, budget, color, and the materials of each design element such as flooring or walls are handled by some platform. Recently, these types of the web-based platform have emerged with the increased interest in housing and built environments in Korea, but are currently immature and small-scale. Thus, there is not currently any well-organized reference management platform that covers Korean interiors and housing design.

The current management system has some problems. First, despite the efforts of the platform manager, the labeled design features of the actual design reference instance often do not match the correct features, except in cases of the best or most popular reference feeds. This may be because such images should be manually uploaded, classified, and validated by the platform users or manager, so it costs significant human resources.

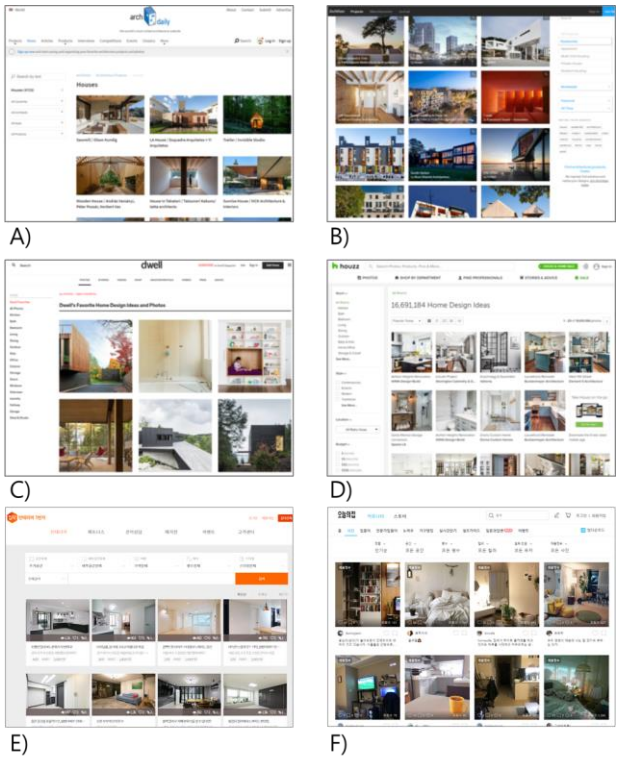


Fig. 2 Examples of popular architecture and interior design image reference platform. A) and B) are architectural design reference platforms. C) and D) are more related to interior design. E) and F) are interior design platforms in Korean.

The second problem is related to browsing or searching for images that a user wants to find. Generally, users have two options: just clicking and browsing with categories or typing some keywords. These methods are sometimes not useful because the references are > 100 pages. Therefore, potential references are rarely found. In the future, there will be an urgent need to develop a method for finding appropriate information in situations where more design cases have become complicated. In terms of the good management and utilization of a reference images database, an intelligent approach such as automatically classifying and saving the feeding digital images that are scanned or taken and powerful data retrieval function for images is helpful.

Table 1: Handled feature related to housing design on the most popular image reference management platform in the world and Korea

Platform	Design Features Handled						
	Use	Style	Designer	Country	Size	Budget	Materials
A	-	-	O	O	-	-	O
B	-	-	-	O	-	-	-
C	O	-	-	O	-	-	-
D	O	O	O	O	O	O	O
E	O	O	-	-	O	-	O
F	O	O	-	-	O	O	-

3. Managing Design Reference Images using a Deep Learning Mechanism

3.1. Approach

Recently, various studies to make computers understand and execute domain-knowledge have been conducted in the AEC/FM industry, such as BIM-enabled automatic rule-checking and analysis according to the design situation from the early phase of design to facility management [6, 8, 19, 21]. How to translate domain-knowledge into a computer-readable format is one of the most important issues [9, 10, 16, 22, 23]. This paper proposes an approach to intelligent reference image management to imitate the interior design domain knowledge using a deep learning mechanism; we focus on automatic classification and stochastic keyword-based or visual similarity-based image retrieval methods.

Computer vision deals with how computers can be made to gain a high-level understanding from digital images or videos and seeks to automate tasks that humans can do themselves. The deep artificial neural networks—shorten to "deep learning"—have achieved great success and are now known as the most powerful and popular machine learning mechanisms. The deep learning mechanism enables computational models composed of multiple processing layers to learn representations of data with multiple levels of abstraction [15]. Convolutional Neural Networks (CNNs) with deep learning is most commonly applied to various computer vision applications such as facial recognition or animal classification. Figure 3 shows the typical structure of CNN data processing.

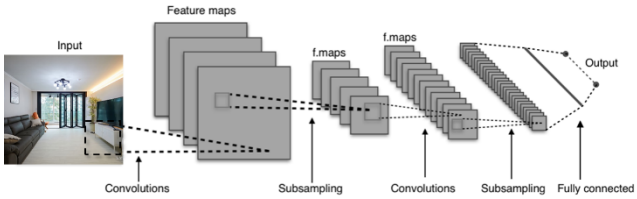


Fig. 3: General architecture of convolutional neural networks for image recognition technique [15].

The convolutional and pooling layers in CNNs could be understood as imitations of human neurons [15]. After each image is processed according to the CNN flow, the image feature map data (a.k.a. bottleneck data) is generated and is used for training. A detailed description of precisely how it works is beyond the scope of this paper and so is skipped. There are many open-source frameworks to help non-experts train their own deep learning models. Among these, the tensorflow framework [1] is the most supportive of other domain researchers, so we utilize this; it supports the Windows OS and provides pre-trained image recognition models and a Python language interface, so training work can be done relatively easily. In addition, to compare other open-source frameworks, there are many users around the world, the community is active, and many tutorials and documents have been translated into Korean. The tensorboard, which is a visualization tool for a better training environment, is also provided.

Training a deep learning model from scratch requires significant time, computer resources, and data, thus models that have been pre-trained by Google or other computer vision research teams are generally reused. We have reused a popular and powerful pre-trained model called inception-v3. We only retrained the linear classifier and reused the main body layer that extracted the abstract image feature map data. This is a common way when the new dataset for training is small and similar to an original dataset that was used in previous training processes. Through this approach, we can finally get two re-trained inception models with categories about our scope, room use, and living room design style. The results of automatic recognition are shown by category and probability value, which is used for automatic classification and stochastic keyword-based retrieval.

Approach to developing visual similarity-based retrieval is based on the T-distributed Stochastic Neighbor Embedding (T-SNE) [17] and measuring the Euclidean distance. The machine learning algorithm for visualization is T-SNE, which is a nonlinear dimensionality reduction technique commonly used for embedding high-dimensional data in two- or three-dimensional space. Specifically, it models each high-dimensional object by a two- or three-dimensional point in such a way that similar objects are modeled by nearby points and dissimilar ones are done by far points with high probability. Figure 4 shows an example of the visualization of clusters according to visual similarity using T-SNE with an aspect of the interior reference image data. A) shows how data is distributed with different color points according to pre-classified categories where similar data are clustered with high density and B) visualizes the same results with the images

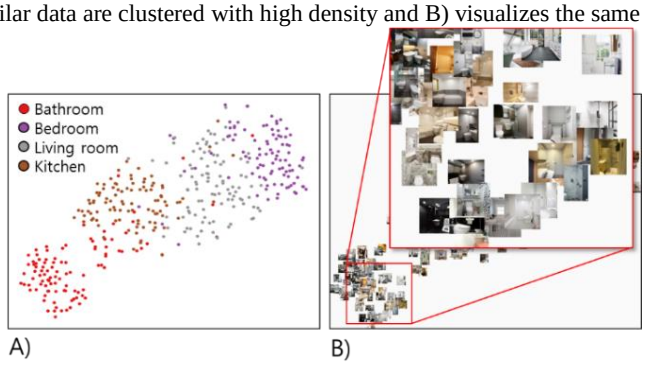


Fig. 4: An example of the visualization of similarity between a part of the interior reference image data using feature map data generated from the inception model[17].

3.2. Scope of Work

This paper proposes an approach to managing an interior image using an automatic recognition technique and its prototype application is demonstrated. The main method is to reuse a pre-trained general-purpose image recognition model to extract the feature map from the interior image and retrain the classifier layer with design domain knowledge. The interior design covers individual design elements such as the walls, columns, volume, furniture, materials, and lighting. However, the interior design is recognized through the integration and harmony of all elements. We trained two models in total, one for room use and the other for the living room design style (e.g. Figure 5). It is common to classify design styles according to the room use because each room has different design components so the overall harmony differs. Therefore, we followed this approach.

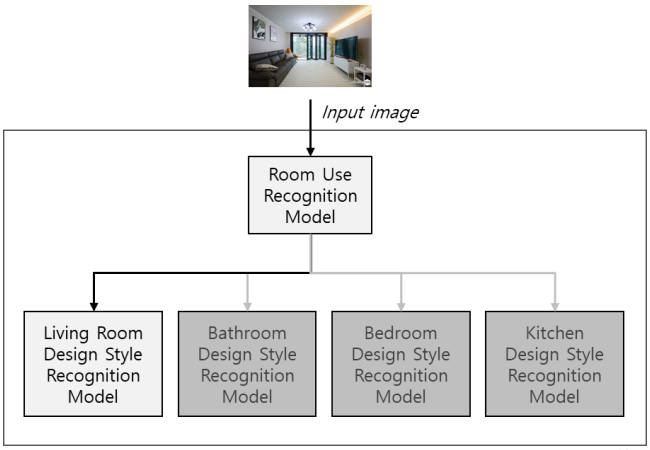


Fig. 5: The scope and process of image recognition in this paper. It is necessary to separate models that have different criteria according to room use.

We focus on training the entire view of the interior image. The target interior design image is an apartment room in Korea and the categories are limited to common four room use and four popular design styles of living room. Figure 6 shows their representative images; first, the room use includes bathroom, bedroom, living room, and kitchen, which are common in Korean apartment planning. We try to collect different images that show well clear and the entire room, regardless of the professional image or smartphone image from the mentioned platform and real estate website. Second, although the design style is an important feature, its definition or criteria are very ambiguous and some design styles overlap each other such as modern design and the Scandinavian design style. Therefore, we would not clearly define some design styles and train the model to recognize perfect design style rather focus on training the common design style that is roughly accepted as each design style. The scope of this paper tests the automatic recognition of design feature like style and shows the possibility, rather than cover all design features or styles. For this, only the most popular or uploaded by designer images that are classified as a specific design style on the mentioned platform are used to secure reliability. The target is limited to four popular and distinctive design styles (casual, classic, modern, and natural design style) of Korean living rooms [11].

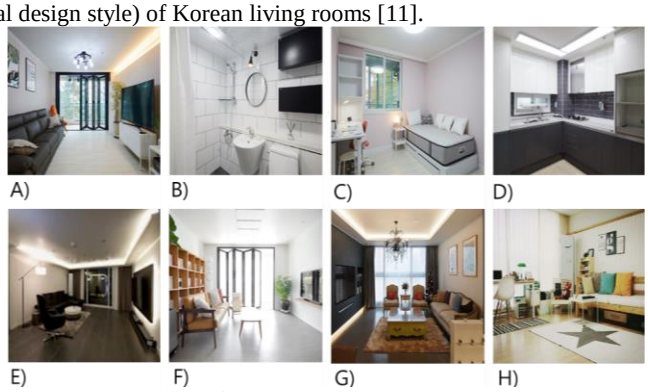


Fig. 6: Representative images of four common room uses and the four most popular design styles in Korean apartments. A) is a living room, B) is a bathroom, C) is a bedroom, and D) is a kitchen. E) is the modern style, F) is the natural style, G) is the classic style, and H) is the casual style.

4. Auto-Recognition of Design features on Interior Design Reference Images

4.1. Data Preparation

The Korean apartment interior images are collected from various platforms to share interior design information and images in Korea. Various distinct and clear professional indoor images have been taken by experts and non-professional images taken by amateurs on smartphones with the correct labeling of room use (bathroom, bedroom, living room, or kitchen. We could get various images with different perspectives and this is needed for making practical applications with the automatic recognition model. In total, 4,000 images were collected. 1,000 images were used in each category of four room use.

The images involving the design style of the living room are collected from the platform that covers the design style feature of interior design images. The target is not limited to Korean apartment rooms but includes general living room design images. As mentioned, we would not try to train the perfect modern or classic style, rather we train on designs commonly recognized as specific design style cases. Therefore, we collected only design style images that interior design experts label and classify into specific design styles in the source site and the target design style is limited to four popular and distinctive design styles (classic, modern, casual, and natural style) Among the collected images, images that have unclear or ambiguous design styles are excluded. In total, 880 images were collected. 220 images were used in each category of four design styles. As the collection criteria for the style are more restrictive than the room use, as mentioned above, the number is smaller, but Some 200 cases are proper for general test purposes, such as the Oxford-IIIT Pet Dataset [29] that is one of the most popular animal image dataset for deep learning based image recognition.

The collected images should be classified so that they do not overlap in the training and testing process. Overfitting, which means when the model cannot classify images that were unused in training but do well with images that were used for training during the training, was avoided, while non-overlapping training sets and verification sets were used. Eighty percent of the total images were used for training and 10% were used to validate the training process. The remainder was used to test how well the new images were recognized.

4.2. Training Models on Interior Design Reference Image

We utilize the pre-trained inception-v3 model to extract feature data from the image and re-train the linear classifier according to our categories. The model's configuration was divided into two: room use and design style. Two different models were integrated into the automatic recognition application. Setting the hyper-parameters for training means some setting values, we control the training steps, batch size, and learning rate. The final best result is shown in 10,000 training steps, 100 batch sizes, and a 0.015 learning rate. The training of room uses and living room design style took approximately 40 minutes and 30 minutes, respectively and the training results are presented in the next section with the testing results.

4.3. Testing the Models

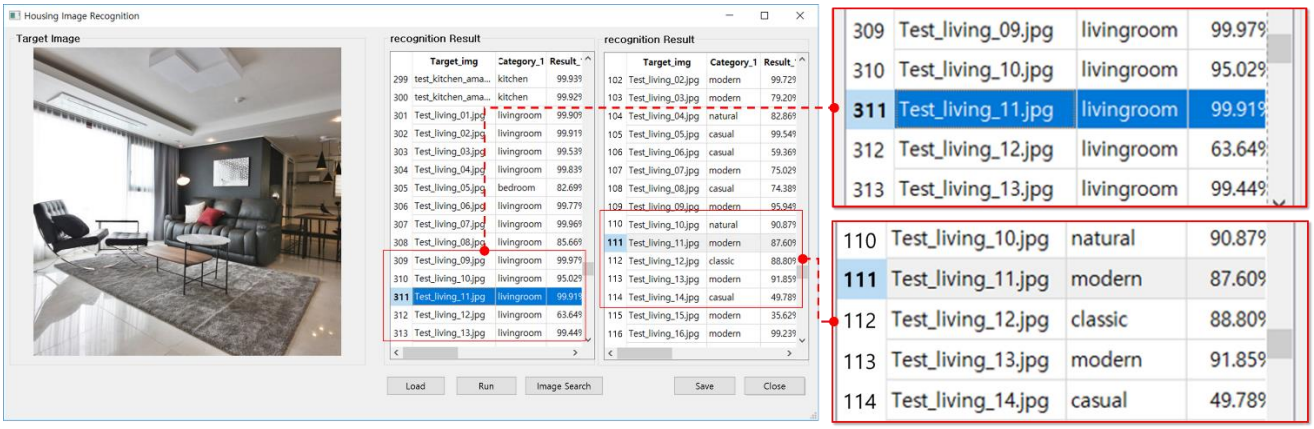


Fig. 8: GUI Interface of the application prototype and examples of visualization results of the auto-recognition on right red box. Each column means the following in order: 1) numbers, 2) names of target images, 3) first categories, and 4) its probability value.

This section describes the tests for two trained models. Test datasets include images that are categorized separately during data preparation. The images do not overlap with the training set but are collected in the same manner. The test for room use is performed using 400 images in total with 100 images from each category: bathroom, bedroom, living room, and kitchen in just 65 seconds. The test for the living room design style is performed by using 80 images in total with 20 images from each category: casual, classic, modern, and natural. The test results are stored in a dictionary format through an automatic recognition module implemented in Python and are finally converted to the xlsx format for easier analysis. The examples of test results are as shown in Figure 7 and the recognized category and its probability value for that image are represented.

	A	B	C	D	E
1	Target_img	name_1st	score_1st	name_2nd	score_2nd
2	Test_bath_01.jpg	bathroom	0.99851	kitchen	0.00146
3	Test_bath_02.jpg	bathroom	0.98780	kitchen	0.01064
4	Test_bath_03.jpg	bathroom	0.99936	kitchen	0.00059
5	Test_bath_04.jpg	bathroom	0.99917	kitchen	0.00080
6	Test_bath_05.jpg	bathroom	0.99979	kitchen	0.00016
7	Test_bath_06.jpg	bathroom	0.99976	kitchen	0.00023
8	Test_bath_07.jpg	bathroom	0.78091	kitchen	0.20258
9	Test_bath_08.jpg	bathroom	0.99970	kitchen	0.00028
10	Test_bath_09.jpg	bathroom	0.98429	kitchen	0.01557
11	Test_bath_10.jpg	bathroom	0.98335	kitchen	0.01626
12	Test_bath_11.jpg	bathroom	0.93586	kitchen	0.02637
13	Test_bath_12.jpg	bathroom	0.99840	kitchen	0.00149
14	Test_bath_13.jpg	bathroom	0.99880	kitchen	0.00082

Fig. 7: Example of results of recognition testing for room use. The result includes categories and probability values to five decimal places.

This is a very important point that unlike traditional binary methods of storing and retrieving data that can only distinguish between true and false, this provides the ability to store and retrieve data with rank and probability values. This recognition approach can well suit the management of reference images, since design features are often considered overlapping or conflicting features such as modern and natural-style living rooms, rather than only being included in a particular category. We determined how to well perform recognition by analyzing the correct answer rate and average accuracy when the answer was correct (e.g. Table 2).

Table 2: Results of automatic recognition test of room and design style

Model	Category	Training/ Validation	Testing	
		Correct Answer Rate	Correct Answer Rate	Accuracy
Room use	Bathroom	90.1%	96.5% (386/400)	89.8%
	Bedroom			
	Kitchen			
	Living room			
Design style	Casual	75.2%	70.3% (61/80)	70.4%
	Classic			
	Modern			
	Natural			

As a result of the automatic recognition test of Korean apartment room use, the correct answer probability was 96.5% and the average probability value was 89.8 when the answer was correct. However, in the case of design style, the correct answer probability rate was 70.2%

and the average probability value was 70.4%; this seems due to the difference in data quantity and quality. The design style is more diverse and complex than that of room use.

5. Demonstration

5.1. GUI Application

Using trained models and the Python GUI interface development library, we developed the application prototype. This application focus on functioning running the automatic recognition, visualizing results, and retrieving and saving results (Figure 8). Two different types of data could be loaded. The one is the image set and the other is xlsx file that is the results of operating automatic recognition. After some new images are loaded and run, images and their results are presented in the table view on the right side of the application window. The application visualizes the recognition results of room use, and the design style if it is recognized as a living room with the highest probability. A user could check the results and delete some rows if the recognition was incorrect so this results could be used for the new training set. In this way, the performance of the application could be improved with new validated data by the user. The xlsx file and configuration of images could be saved on a specific database. Image retrieval is performed by selecting an option in a new pop-up window and executing it, and then the results are displayed in the main application. There are two options for image retrieval.; the stochastic keyword-based retrieval and the visual similarity-based retrieval.

5.2. Stochastic Keyword-based and Visual Similarity-based Retrieval

This section shows the retrieval functions using the results of automatic recognition and method that measures the visual similarity. First, stochastic keyword-based retrieval methods utilize the category name and probability value of the results of automatic recognition. Users could set the value of multiple categories with and/or logic operations. Therefore, it is possible to search some strings with certain probability values; this helps to search for certain conditions. For example, users could search for interior images with > 90% (which means more than 90%) probability of being a living room and > 60% probability of being in the modern style and > 20% probability of being in the natural style. Figure 9 shows the interface on the GUI application. Therefore, it is possible to search some strings with certain probability values; this helps to search for certain conditions

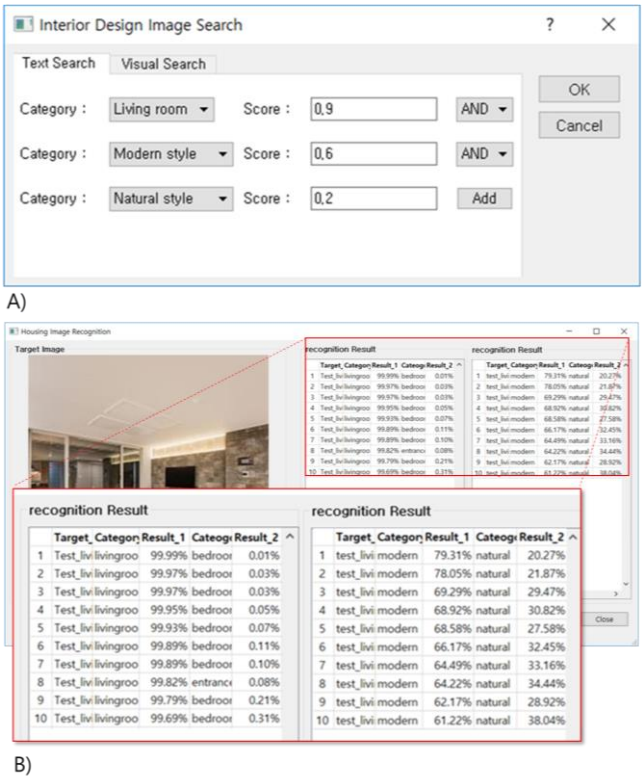


Fig. 5: Example of the stochastic keyword-based image search interface. A) Stochastic keyword-based retrieval options. B) Results of the main application.

Second, the visual similarity-based retrieval method utilizes image feature map data and the t-SNE algorithm. By reducing the dimension of the feature map, the distance between each data could be calculated. The distance means similarity. The user just put the source image on visual search tap and set the number of the retrieved images. This method is not directly linked to previous room and design style recognition model, but the user utilizes the results of stochastic keyword search. These approached help users to find out reference which they are looking for with more specific condition. Figure 10 shows the example of the visual search.

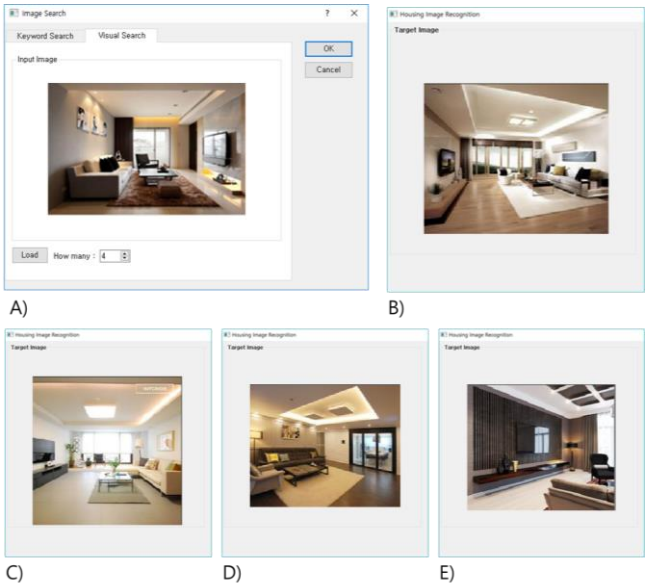


Fig. 6: The example of the visual search. A) is the visual search option window and B)-E) show the capture images of results in the main application according to the ranking of similarity.

6. Conclusion

This paper demonstrates an approach to managing design reference images using the automatic image recognition system. The image recognition system used in this paper includes automatic classification and visual similarity measurement using the convolutional neural networks inception-v3 model and T-SNE. Using the system, we tested the automate classifying, storing and retrieving the Korean apartment room design reference images and showed the possibility to be used as an intelligent reference management.

The target is limited to certain housing rooms (specifically the bathroom, bedroom, living room, and kitchen) and some most popular design styles (casual, classic, modern, and natural styles) in Korean apartments design. The image recognition models are re-trained with the mentioned two interior design domain criteria with 4,000 images for room use and 880 images for design styles. Testing results in the room use case showed that the correct answer rate probability is 96.5%, and the average probability value is 89.8% when the answer was correct. However, the case of the living room design style room showed that the correct answer probability rate was 70.2% and the average probability value was 70.4%. This is because the design style shows significant variation compared to the room use. The data needs to be supplemented for better performance.

Using this model, we developed a GUI interface that supports the automatic recognition of image feeds and visualizes the results. Users could feed their own images, check, delete, and save the results. Through this, interior designers or other interested people could easily and efficiently manage their design reference images. Furthermore, users could retrieve reference data in two different ways: stochastic key-word-based and visual similarity-based retrieval.

The proposed approach ultimately aims to develop an intelligent and supportive design reference management system. This paper is covering very limited categories of features related to housing design but shows the usefulness and expandability. For ensuring the reliability of performance, it is needed to cross-check and refine the model with architects or interior design experts and expand the number and types of data. As further research, it is needed to integration approach to recognizing individual design element and its design feature and integrating it with the way shown on this paper.

Acknowledgement

This research was supported by a grant (18AUDP-B127891-02) from the Architecture & Urban Development Research Program funded by the Ministry of Land, Infrastructure, and Transport of the Korean government.

Discussion

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