Abstract

A generative design system subdivides a real physical space a user actually lives in and recreates it through object-oriented programming, and depending on the situation of the design process, variable data are arranged in a hierarchy to set up parameters so that an efficient shape can be drawn. A pleasant environment of the user space is considered under various space-related conditions during the design process using data obtained from an environment analysis simulation based on the building code. This study focuses on the methodology of processing and utilizing variable data derived by the parameterization of the analysis data through a simulation using sensor measurement equipment to analyze user behavioral design patterns and obtain the intensity of illumination of the interior space, which is the spatial variable data element that forms the actual physical space. After systematizing the variable values through motion capture, during the process of designing, as a sketch, a design algorithm will be formed, which will be utilized as the generative design algorithm. Further, a method for improving the design quality using a computer-based design algorithm will be investigated, and whether the design method can be improved further will be predicted. Relevance to Design Practice – This study utilizes various sensor-based IT technologies and environmental analysis data to design an optimal solution fit for a user environment and investigates whether a methodology could be applied to the design process to help improve the design through a generative design system by the processing of variable data.

Keywords: generative design system; parameter; design algorithm; freeform furniture design; Natural User Interface (NUI)

1. Introduction

Recently, as the demand for mental affluence instead of material affluence is increasing, demand for the study of user-friendly designs that consider the actual physical environment from the user's perspective is also increasing. As a result, various studies are conducted by utilizing human behavioral patterns for improvement of the quality of life as well as sensor technology to measure data for such research. At the beginning of the personal computer age, from the perspective of user interfaces (UIs), data were input using a keyboard and a mouse, whereas the output was displayed on a monitor, a rather limited visual image-oriented function. With the emergence of smart gadgets, as well as the evolution of a ubiquitous idea and sensor technology, various devices can be freely used in human life irrespective of location. Therefore, a user-oriented interface in the computing environment has overcome the spatial limits produced by a monitor or a screen and has provided a three-dimensional synesthetic experience. Of the techniques that help to efficiently generate a measurement process without placing many constraints on the daily lives of users in terms of establishing a tie with a computer system and enabling precise data to be applied in the design process, this study will apply the NUI technique. NUI is a technology that integrates data using a digital device by analog means whereby it provides an invisible interface, which users hardly recognize as a device while using it.

The Mobile-Centric Application and Interface was selected as one of the ten rising technologies of year 2012 by Gartner, a leading American IT research & advisory company, which emphasized the promising future of NUI and predicted that "UI with windows, icons, menus and pointers will be replaced by a mobile-oriented interface that emphasizes touch, gestures, search, voice, and video". In other words, it was predicted that a UI where an order will be passed on and the interactions carried out based on natural human behaviors such as touching, moving, speaking, and thinking will attract considerable attention (Fig.1.).

The existing virtual environment (VE)-based research utilizes virtual reality (VR) to interact with users. However, a

How Do Technology Trends Impact the Human, Business, IT Experience?

Fig.1. Forecast of Ten Core IT Technologies
VR system has some limitations in terms of providing design alternatives by focusing considerably on providing users with a sense of reality because it displays the user environment using computer graphics within a virtual environment. In order to attenuate such problems, an NUI-based applicable technology is required where data are accumulated and utilized using sensor technology to implement the real environmental conditions by a computer.

As a means to analyze human behavior, a motion sensor that is attached to a person's body or used through a handheld device has been widely used for movement recognition, which is one of the NUI techniques. However, in order to minimize the sense that the user of such a device feels, an infrared and a depth sensor are used more commonly these days. In this study, in order to build the data to be used for the design process, of the many NUI techniques, we will use a technique in which scanned data will be digitized and saved in the database before the motion data are mapped in the virtual space. Variable information accumulated from the motion data will conduct a procedure linking the pre-existing design process. The most considered fact to utilize the design process is to decide how to use the accumulated information, and through such consideration, meet the requirements of the basic plan of the design process and create a plan that can meet the user's demand through the use of a shape-recognition algorithm. A design process, implemented as described later in this paper, will provide designers who are non-experts in computer systems with expert analysis data through a generative design system, and help them in their design activity by synchronizing alternative designs.

2. Parameter Generation and Analysis through Synthesis

The generative design system is a process of resolving design problems according to the environmental conditions of the architectural space. Such a design process goes through steps where the important aspects of the design problems are analyzed, and a resolution is obtained based on the analyzed data. Then, the resolution is assessed through an examination phase. LAWSON explains the phenomenon where designers do not use a sequential-problem-solving method, but a simultaneous method, where many stages are conducted simultaneously to identify and resolve design problems, such as "analysis through synthesis."

The main method that a designer uses in "analysis through synthesis" is sketching, where the resolution to the problem is drawn up by brainstorming and discovering a new perspective to the problem, which then leads to the creation of a new idea (Robbins, 1994, Goldschmidt, 1994). This is because through sketching, it is possible for the designer to explore something new, which was not predicted nor anticipated during the design process (Goldschmidt, 1994, Schon and Wiggins, 1992). This is a somewhat unexpected discovery (UXD) acting as a catalyst for new ideas. Therefore, it could be said that when a designer's idea surfaces by visualization, the designer can review the idea and develop new ideas and resolutions. Publicizing the idea can solve the problem as the next step, and such a resolution would be a design alternative. This could be inferred as the designer reviewing various alternatives of situation-based variable data to further improve the design. However, there could be limitations in building alternatives and reviewing with sketching alone. Limitations in human information processing capability places a certain limitation on creating various alternatives. The generative design system can be employed to overcome such limitations. The generative design system is a theory that has been in use since long before the computer was developed, and with the evolution of computers and the development of sensor technology, design studies applying such a system are gaining a significant amount of attention.

Another issue is that with conventional sketch methods, potential problem spotting, comprehending, and reviewing new solutions of an atypical geometric form has limitations when used as a medium. For example, in a case where a further objective and logical process is required, such as in designs utilizing environmental analysis information of the space, the designer will need a medium other than a sketch. In this study, we want to develop a design process that uses the environmental information of the space and propose an objective data-based design alternative utilizing environmental information for implementing what the designer intends to form instead of using something based on intuitive data.

2.1 Research Method and Procedure

The objective of this study is to implement a generative design system (Janssen, 2002) and conduct the process on the assumption that an effective design can be obtained by inserting parameter data that are a result of the synthesis of the user behavioral analysis data and the environmental data during the design process by the design algorithm (Chase, S. 2002). Following the results of the process, we will attempt to identify the possibility of applying the variable data through the digital design tool of the generative design system. Priority will be given to the development of a system that can utilize a design algorithm with a motion recognition technology of the Kinect equipment.

The process of this study is illustrated in Fig.2. First, the need for the generative design system is comprehended and the major design algorithm for the generation of the form design is selected. The direction and design standards for development of the design of a freeform bookshelf are set, which is going to be the result of this study.

Second, an actual physical space is selected and the interior illumination analysis simulation data based on the spatial coordinates are stored in a spreadsheet-type database.

Third, the user's behavioral patterns inside the physical space are obtained through the motion recognition equipment and the major behavioral pattern data in the aforementioned are stored in the spreadsheet-type database (Fig.3.).
Fourth, the variable data information accumulated in the database is synthesized after optimizing it into parameters through evaluation index.

Fifth, the synthesized parameter is applied to the attractor algorithm, and then, based on the result obtained through the feedback process, a generative design system is proposed using computer algorithms and any possibilities for improvement are checked.

3. Generative Design System

A generative design system is a design system based on a generative system. This system can help during a designer's inference process when designing a design alternative and by intervening in the middle of the process. The argument that a design process based on a generative design system and the conventional paradigm that expresses a process can be changed (Khun, 1996) is possible because the generative design system supports the philosophy of viewing the world from the point of view of the output, which results from a dynamic process and methodology related to such philosophy.

A generative system can help the designer's inference process when working on a design alternative and by intervening in the middle of the process. Furthermore, the system can help the conceptualization of the design by the output of the system resulting from the interaction among each design component, process, and system. Such a creation process is based on the unique attribute defined by the designer and the generative design system. The generative process can help the designer's design thoughts by generating various alternatives based on various correlations of the surrounding environment stemming from the early design form, which was the beginning of the designer's design concept. A generative design offers an innovative method diverging from the pre-existing design conceptualization process, and the related studies can be viewed as having their foundation in the idea of synthesis, which is generally found in nature (McCormack, 2004).

4. Design Algorithm

4.1 Need for Applying the Generative Design System using Algorithm

The basic concept of this algorithm is that it is a list of a limited number of orders required to mechanically perform executable functions, and it is the processing part of the course consisting of input, execution, and output. In other words, it is an order of how to process the input contents. A design algorithm can be defined as the organization of the process of generating design outputs by the design intent in response to the design demand (Stiny, G. and Gips, J. 1978). A design algorithm can also be referred to as the design process, and an algorithm-based design is a logical definition of such a process in a mathematical form (Ji. S. Y. & Jun. H. J. 2010). In an algorithm-based design, which is a method for developing propagation-based parametric modeling, expressing the correlation among the variables and mathematically expressing the logical structure of the overall design are an important technological component of the design generation system. Through algorithm-based design, which is a method of delivering the design intent of the designer to the computer, the computer can calculate the design and logically and systematically process various complex design types.

The algorithm-based design process is expressed by object-oriented programming after subdividing the variable data of the actual physical space into each individual component, and the design elements are classified into hierarchical groups corresponding to each situation. Further, by setting up the premeditated demand elements as the condition, the algorithm responds to the various spatial conditions considered during the design process. The goal is to have an overall design process that can develop design alternatives faster than the design process conducted by the designer's subjective decision. The repetitive analysis conducted to implement an efficient form suitable to the user environment during the design process naturally calls for a repetition in the capacity test and a design change of the planned form. Generating alternatives by repetitive simulation until a satisfying assessment that fits the effective standard is obtained is time-consuming. In contrast, a design algorithm cannot be viewed as a method superior to the creative mind of a human being. Further, the reproduction capability that repetitively creates a certain target value could become a catalyst in the feedback process with the parameter. In order to resolve this problem, in this study, we utilize the form generation method using a design algorithm.

Expert knowledge is required to comprehend the environmental analysis tool and the user behavioral pattern analysis before applying the obtained observations to the design. The method of the design algorithm utilizing the generative design system applied to the parameter is time and
cost efficient because this method makes it easy for variable data from the actual environmental condition analysis to be applied to the design. By adding credibility to the extracted data and setting up the variable needed for form generation according to the designer’s demand, we can verify the advantages and disadvantages of the design efficiency and spatial capacity of the generated form, as shown in Fig.5.

Fig.5. Need for Applying the Generative Design System

4.2 Development of a Design Algorithm Prototype

The attractor algorithm applied in this study is a type of design algorithm applied to the generative design system after referring to the form generative library developed by Hertmut Bohachker (Fig.6.). The algorithm was developed using two classes, Attractor and Node, which are part of the generative design library. The user's pattern from the motion capture information and the illumination analysis data function as components for user convenience and generate the form using the distance between the Attractor and the Node as the criterion. The nodal points in the coordinates of the space of the form refer to the Node and provide diversity to the form by the Attractor, which plays the role of a magnet. The nodal points of each coordinate generate the form by the pushing and pulling power of negative and positive poles depending on the analysis method. The advantage of real-time feedback of the analyzed variable data is the significant characteristic of using the attractor algorithm in generating a form design. Hence, effective variable management is possible, and even with minimum variable variance, the gradual change in forms are significantly noticeable.

The main equation to depict the volume calculated from the gradation of the attractor algorithm is equation (1), where the distance (d) between the node and the attractor of Fig.7. is calculated, and then, the attractor domain is defined as the input variable radius (r). The f, which is the force of the attractor, value from the graph in Fig.7.(a) is set to be inversely proportional in equation (1), and the velocity vector value is gradually applied to each node value depending on the attractor domain. The distance value of the attractor attribute and the influence of the vector are displayed in the correlation graph for the generation of a freeform surface. Fig.7.(b) is the graph displaying the vector value for the movement of the node where the easiest method to synthesize the node and f is the multiplication of d and f. Further, the moving distance or reaction speed of the nodal points is set to decrease as the distance value (d) becomes closer to 0 or closer to the radius value (r).

5. Algorithm Applied Design for Actual Physical Space

A bookshelf is to be designed using the parameter-applied design algorithm. The reason for choosing a bookshelf is that a bookshelf makes it necessary to consider various aspects of the design such as the user behavioral design patterns in the actual physical space and the interior environment condition as well as the size of the books. It is necessary to make it easy to insert it into the generative design system through a refinement process of the variable data suitable for the following necessary condition item. As for the environmental condition, 300~600 lux, which is the recommended illumination intensity value for an ordinary office environment, must be guaranteed and the quality of the light must be maintained despite the changes in the layout or the purpose of the office space (Fig.8.). (KS A 3011-1993, Korea Building code)

5.1 Variable Setup

5.1.1 Environmental Condition Variables

(1) Selection of Environment Analysis Tool

According to the comparison study of the BIM-based environment analysis tool by Salman Azhar and Rizwan Farooqui, the Solar and Lighting and Day lighting analysis technique in Ecotect of Autodesk Inc. was selected for use after comparing the environment-friendly analysis program with seven items of energy, temperature, sun, illumination intensity, sound, maintenance cost, and LEED. The decision was also taken considering the fact that the analysis method is based on a space coordinate analysis, which was not used as an analysis tool in other comparison studies.

Fig.8. Applied Design Plan of the Attractor Algorithm

Fig.7. Mathematical Expression of Attractor Algorithm
In order to extract the parameter, the interior natural light and the illumination intensity value of the actual physical space were used as the analysis value. First, in order to compute the numerical data according to the natural light, a simulation was conducted using a program called Radiance to determine the percentage of natural light in the overall interior illumination intensity. Natural light was analyzed through DAYSIM, which can analyze the annual interior illumination intensity using weather data. The analyzed information became the standard for the analysis of the exterior environment using the weather data of the Incheon area provided by the U.S. Department of Energy (DOE). An attempt was made to build variable data that can change a form, following a comprehensive analysis of the interior illumination data from artificial light and analysis data of the natural light coming from the exterior environment using the weather data.

(2) Building Environmental Analysis Data

A research lab of the science technology hall of H University as shown in Fig.9. was selected as the actual physical space where the generative design system was applied; the building is oriented to the southwest and built based on the building information modeling (BIM) method for environment analysis. The space of the building was analyzed through the environment analysis tool and then converted to the gbxml format, which is compatible with the environment analysis tool. The exterior illumination intensity was set to be 20,000 lux considering the latitude of the location of the building and the time being noon.

A shadow analysis was conducted from 9 a.m. to 5 p.m. As a result, it was confirmed that the object was located within a permanent shadow area. However, there was a characteristic that reflected light was flowing into the building from a building located on the opposite side where the distance was less than 0.8 m.

In this study, in order to use the sunshine analysis and interior illumination intensity analysis variable as the shape change variable, the annual analysis was conducted by ray tracing of the reflected light as shown in Fig.10. Since the winter season from November to January was just about the only period where the reflected light continued for more than an hour during the day, the sunshine analysis was conducted during this season, and the overall daylight and electric light level including the external illumination value and the internal artificial illumination value was analyzed.

Fig.11. shows the calculation of the parameter data of the major time slots through an interior illumination simulation. In order to obtain the recommended illumination value of 300–600 lux suitable for ordinary office work, which is also the recommended design standard in architectural design, the illumination values of the entire three-dimensional space were calculated at the standard scope between 1.1 m and 1.6 m, which is the level of the major work space.

5.1.2 User Pattern Variable

Kinect is a line of motion sensing input devices by Microsoft. Based around a webcam-style add-on peripheral, it enables users to control and interact with their computer through a natural user interface Kinect software development kit released for Windows 7 in 2011. This SDK was meant to allow developers to write Kinecting system in C++/CLI, C#, or Visual Basic .NET. Kinect, which developed a system that can interpret specific gestures, making completely hands-free control of electronic devices possible by using an infrared projector and camera and a special microchip to track the movement of objects and individuals in three dimension. This 3D scanner system called Light Coding employs a variant of image-based 3D reconstruction.
Kinect sensor is a horizontal bar connected to a small base with a motorized pivot and is designed to be positioned lengthwise above or below the video display. The device features an "RGB camera, depth sensor and multi-array microphone running proprietary software", which provide full-body 3D motion capture, facial recognition and voice recognition capabilities. The depth sensor consists of an infrared laser projector combined with a monochrome CMOS sensor, which captures video data in 3D under any ambient light conditions. The sensing range of the depth sensor is adjustable, and Kinect software is capable of automatically calibrating the sensor based on gameplay and the player's physical environment, while accommodating for the presence of furniture or other obstacles (Fig.12.).

(1) Motion Recognition User Pattern Value

After finishing the simulation regarding the light fixtures and external light, in order to reflect the user behavioral design patterns, the elementary information was limited to arm length, sitting height, and grip, and then, the radius of the user rotation displacement value was reflected in the design based on the height, sitting height, and arm length of the four people using the space. The users' numerical information was predetermined before the sensor measurement in order to prevent any error from occurring. Physical information such as the radius of the arm rotation and the sitting height was set as the limit of the maximum activity domain and utilized as a basic guide of the form design and to minimize the errors that might occur during the sensor measurement.

(2) Utilizing User Pattern Analysis of NUI-Based Motion Recognition Equipment

"We must suit humanity to technology before technology hacks humanity." (Oliver Sacks,)

Following the principles depicted in the comment by Oliver Sacks, in order to suit humanity to technology in a simple way, to learn and comprehend humans, and to react immediately to their needs and desires, Kinect, a motion recognition device, was used. The raw depth data created from the equipment has a limited usage range, and as shown in Fig.13.(a), two depth views are used for observing the user. However, since the basic Kinect equipment's observation range is 4–8 m, which is not suitable for close-range observation like watching a person working in front of a desk, a Kinect zoom with the observation range of 0.8–3 m was used. The method used by Kinect is called skeleton tracking and utilizes the depth data of the pixel to collect a person's motion capture information. Skeleton tracking is a process of drawing a contour of the object using the depth image data in order to find the joint location of the human. For example, skeleton tracking decides where the person's head, hand, and center of mass are located. Skeleton tracking provides the X, Y, and Z values of each skeleton point. Each coordinate value measures the joints of humans, and as indicated in Fig.13. (c) and (d), the entire body or separate body parts such as the upper body could be measured. Since this study focuses on a sitting person, the observation was conducted as shown in (c), and the only two parts that the data were extracted for were the coordinates of the left and the right hands.

A 1200-mm-wide and 800-mm-deep desk was assigned to all four users, and the measurement range was limited to the width of one person's desk as for the tracking screen. However, the width of the desk was not measured from -600~600 mm using the person's sitting position as 0, but in order to ease the evaluation index and the use of the pixel method of the Kinect equipment, numbers from -0.4~0.4 were used. The Kinect was located in the center using a stand. The measurement was conducted during the work day, and the data were measured every minute and arranged into left- and right-hand data. Although the nodal point data of all the joints could have been collected, since this was not the objective of this design plan, they were excluded.

5.2 Analysis of User Patterns and Synthesis of Variables

The space coordinates of the user behavioral design patterns extracted by the Kinect were arranged into an excel sheet through a scatterplot matrix so that the major patterns could be analyzed. The width data of a one-person desk went through evaluation index to be defined between -0.4~0.4 horizontally and vertically. The data regarding the height of the hand were plotted on the Y-axis. The origin of the Y-axis was the position of the Kinect lens with an actual survey value of 670 mm, and the origin of the X-axis implied the middle of the desk. Because of the left and right reversal, the left side had positive values, and the right side had negative values. The reason for not directly inserting the actual data measured but using the data after going through evaluation index was to ease the optimization process of the major pattern variables that were used in the design analysis as well as to minimize any possible error occurring in the data system implementation and the algorithm error. The stress on the database was decreased by deleting any value that was out of the defined scope. The user pattern information from the Kinect had left-hand and right-hand data left such as the pattern indicated in Fig.14.

In order to conduct the optimization process of the variable data with respect to the user pattern, there was a need to convert the value in a certain range to a value of another range. Since the value directly supplied from the sensor of the Kinect formed irregular patterns, we used the average value extracted from the evaluation index process. The evaluated data was rounded to the nearest thousand, and the average exponent was calculated. The principle through evaluation index is as follows (Fig.15.).

The variable data selected between -0.4~0.4 was converted into actual data of -600~600 mm, the actual desk width. For example, when the measured data were used for calculating the average exponent (0.25, 0.58) by going through the evaluation index process, the actual space coordinates turned out to be (-375, 1058.6). (Fig.16.). The library used in the next process was the map () function.
5.3 Application

5.3.1 Application Principle of Variable Data to Algorithm

The data produced after the analysis was chosen as a guideline after a comprehensive mutual synthesis between the illumination data and the variable data from the user pattern. As for the user behavioral design patterns considered in this study, the scope was limited to the physical information of the user. Any data outside the scope were discarded. Using the characteristics of the attractor algorithm, which utilizes the combination of the pushing and pulling power, we calculated the illumination value at the user desk, which is the main work space; the corresponding coordinate was given a pushing power (-) to implement a free form of the volume. In contrast, the spatial coordinate variables were set based on the user's behavioral patterns derived from the frequently used space based on the motion sensor, and were given the pulling power (+) to improve the functionality of the figuration for the user. (Fig.17.).

5.3.2 Application of Parameters to Algorithm

The parameters collected in Excel were inserted into the three-dimensional modeling program Rhino using the data conversion system developed using C#. The parameter values were indexed for the ease of implementation and control of the form, and the design algorithm that was pre-worked at the prototype was executed using Rhino Script Manager (Dritsas, 2005). Finally, the data of the form were implemented in the three-dimensional modeling space, and various alternatives were produced based on the parameter values. A generative design system was designed so that the entire process, beginning from the spatial analysis to the final alternative production, was integrated into a single process and that the feedback process could function (Fig.18.).
6. Conclusion: Parameters Could Be Used as Important Variables for Effective Design Implementation

A generative design system based technology can aggregate each information element of the actual physical space into meaningful units and produce, edit, and interconnect them. Furthermore, depending on the mutual relationship of the parameter and the design algorithm, the system can be used to produce various design alternatives using different forms. In this study, research was carried out for the function and influence of the design algorithm and the parameter extraction methodology in the implementation of the design form using the parameter-based mutual relationship design methodology. Furthermore, possibilities regarding the parameters for the addition of the design characteristics required by the designer were also studied. The elements in the algorithm using parameters with respect to architecture were studied and depicted in the design process. In the early stages of the design, parameters were implemented after the illumination intensity simulation, that depicted the actual physical environment and the user behavioral design patterns analysis before being applied intuitively through the mutual relationship between the two parameters, and the actual space design. Even if the designer defined the design in the design algorithm, it could be confirmed with the analysis program applied in the design process and the digital carpentering process that the design could fall within the legal recommendation criteria.

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References

6) Iwasaki, Y., & Low, C. M. (1992). Model generation and simulation of device production and manufacturing as well as considerations in the planning stage must be carried out based on an integrated product design (IPD). Second, this study used the Kinect sensor, NUI-based motion recognition equipment, to analyze the user behavioral design patterns. Yet, a sensor that could consider other environmental elements such as light, sound, bending, pressure, and temperature as parameter data should be used. Third, based on the economic feasibility of the produced alternative, instead of assessing the absolute value, an alternative verification method that can compare all alternatives with the same objective should be studied in order to consider a realistic tool that could think of an actual production stage. This study focused on analyzing the parameter of a design sample, and the method of applying the developed algorithm as well as methods of extracting major parameters. This research was an elementary study to determine the possibility of using parameters utilizing sensor data and environment analysis data through a correlation between the parameters and the design algorithm. Various design types will consist of a significantly large number of variables. If we can analyze the major parameters comprising the physical space, limiting condition, and the correlation and systematically write a numerical equation, a generative design system may be expressed implicitly, and could be used to efficiently produce new alternatives.

Fig.19. Computation and Selection of Various Alternatives