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Elements and Structure of the Smart Lighting Design in the Office

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Objective: The purpose of this research is to extract factors affecting office lighting and their relations, and then develop a framework that helps designers research and design smart lighting systems.

Background: Due to the highly specialized usages of offices, the lighting system within offices also varies according to space, work, user, etc. A framework which considers these various factors and their relations is necessary for understanding and developing smart lighting systems.

Method: First we extract factors affecting office lighting conditions, and select factors that can be controlled. We then analyze and develop a structure which reflects the relations among these factors from procedural perspective.

Results: We divide factors affecting office lighting into physical and social factors, and then conceptualize their relations using a circular model. We then develop our framework from procedural perspective by dividing these factors into three levels, namely Subject, Action and Object.

Conclusion: The developed framework organizes various factors affecting office lighting and their relations, and helps understand the procedural and structural aspects of lighting system.

Application: Our framework helps designing and refining smart lighting system for complicated office spaces by helping people understanding the overall structure of office lighting.

Keywords: Office lighting, Structure of smart lighting, Smart lighting process, Smart lighting

1. Introduction

As an office is a public space where activities for various purposes occur simultaneously, working environments such as temperature, humidity, and illumination are affected by a variety of factors in general. There are many variables to take into account since some factors are organically correlated or in conflict, but most offices control environmental control devices uniformly. This may be because of limitations of the system that has to be manipulated uniformly, but situations are little varied even if it is possible to control different sections of the space specifically. In fact, an occupant who is carrying out tasks is unable to control individual devices to optimize ever-changing work environments, and it is also challenging for an individual to determine and manipulate an opened public space at his own discretion. In particular, it is difficult to determine the proper degree of and notice changes in illumination compared to those of temperature and humidity. Even if it is possible, the occupant would be unable to control every lighting accordingly.

Pack (2006) states that although lighting itself may not be directly linked to work products, it helps a worker readily see details without inconvenience or distraction and distinguish different colors. In other words, appropriate lighting makes it far easier to grasp objects and productivity also can be enhanced as long as the worker is motivated and capable to do so. According to one research of Steelcase (1999) on working space, inappropriate lighting in a working space may cause the productive capacity to decrease, and lighting environment improvement at workplace can decrease eye fatigue and headache as much as 86%. Hence, office lighting not only lights up a room but also affects the work efficiency and condition of the individuals in it. With proper goals and intents, the complexity will increase.

Since an office is a public space with clear objectives, the interior plan and usage can be significantly varied depending on the situations, and it is vital to create environments suitable for each purpose of space use. However, most lighting fixtures are embedded in the building, and thus restructuring a lighting layout in reflection of such changes inevitably involve physical limitations. For this reason, there are increasing attempts to establish a smart lighting system that automatically adjusts artificial light sources at an office as a variety of advanced sensors. For smart lightings to contribute to working efficiency and environment, system types and structures optimized for specific spaces and workers need to be taken into account. This study suggests a frame that can be utilized to embody a practical system by structuring a lighting system process based on fundamental researches related to office smart lighting.

2. Literature Review

Jung and Lee (2009) relate four elements that affect visual performance at workplace: individual deference, quantity of illumination, quality of illumination, and task requirements. Characteristics of each factor are as follows:

If it is possible to group users based on certain visual ability factors such as age, lighting environments can be created accordingly, which will enhance work efficiency. For the quality and quantity of illumination when the working environments are artificially manipulated and adjusted, taken into account are factors such as luminous intensity, quantity of light source on the surface (illumination), brightness of the object (luminance), glare due to the direct light and reflected light of the light source (glare), orientation of the light source, color temperature, and esthetics. Work types may affect the extent of light accommodation, and the specific conditions include the object size, contrast, time of exposure, etc. Since the level of fatigue or stability that a worker feels may be different in a short or a long-time work even in the same lighting environment, settings should be different depending on the work type. To distinguish roles of lighting depending on the space type, Yeo (1999) classifies the usage of office space as well as the main objectives of office lighting-visibility and pleasantness-depending on the space usage (Table 1), clarifying the conditions of lighting in that regard: Conditions for visibility include appropriate illumination, uniformity ratio of illumination, type of direct glare, veiling reflection of reflective glare, and right presentation of colors. Lighting conditions for pleasantness include appropriate vertical plane illumination, continuity of illumination, prevention of unpleasant glare, appropriate light color and color

Table 1. The purpose of the lighting in accordance with each office space (Yeo, 1999)

Usage of space	Utility room	Office	Meeting room	Cafeteria	Lounge
Purpose of lighting	Clarity	Clarity	Clarity, Comfort	Comfort	Comfort

rendition, appropriate luminance distribution, cubic effect and expression of textures, and harmony of artificial light and daylight.

Choi and Ha (2004) states that visual comfort is in relation to the luminance and size of the light source, location of objects within one's visual field, and adaptation of the occupant's eyes. He also adds that the closer the light is to the center of the visual field, the more strictly the general brightness should be limited. The bigger the angle between the light source of discomfort glare and one's vertical gaze is, the less discomfort it causes as shown in Figure 1.

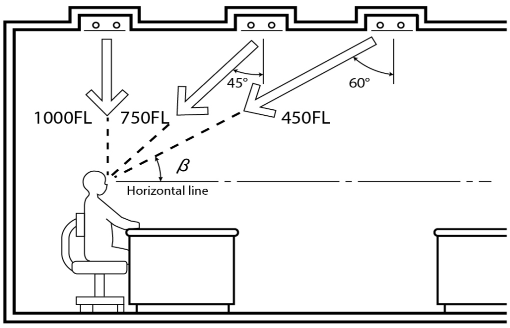

Figure 1. Luminance and visual comfort in office (Egan, 2000)

There could be various types of work at an office, and among these, VDT tasks that cause long-term exposure to strong visual stimulation are closely related to lighting, and the weight of lighting in this effect is absolutely dominant. Choi and Ha (2004) states that it is necessary to prevent reflection on the screen such as CRT (Cathode Ray Tub) and to examine the distribution of luminance on each section indoor, illumination on the vertical plane, and spatial illumination. CIE provides a guideline for lighting in a workspace regarding the location of keyboards and VDT, luminance, luminous panel, reflexive rates of indoor structures, illumination on a horizontal plane, etc. The objectives of lighting environments may be varied depending on the goals, uses, and tasks in office space, and the types of and specific recommendations for lighting may be also changed accordingly. In other words, lighting settings can either enhance or decrease work efficiency.

As for other characteristics of office lighting, there are repeated patterns in space use, and a certain task may be carried out in the same location for a long time. For this reason, patterns of an occupant's movements and motions need to be reflected in planning lighting conditions. In addition, the relation between artificial light sources and daylight also needs to be taken into account for occupants who work for a long time. Yum (2013) examined the effect of LED lighting blind dimming on an occupant's recognition of brightness change. As a result, it turned out that certain factors such as dimming control speed and daylight affected occupants' recognition of lighting brightness change, and that sections where occupants felt discomfort were different depending on the color temperature, which was relevant to dimming control speed. In other words, the complementary control of artificial light sources and daylight is of great importance in preventing lighting change from hindering occupants' work performance, and the change speed of artificial light source brightness is another factor that affects work performance (Figure 2).

Lee (2013) measured the levels of illumination and color in each section of 11 offices to grasp the current conditions of office lighting and compared them with the illumination levels recommended by KS. As a result, it turned out that the actual office lighting environments were significantly different from the recommended standard of illumination. They rather exceeded it to a large degree. This is because it is difficult for office managers to constantly pay attention to indoor illumination while occupants would be readily acquainted with the space condition and become insensitive to the proper level of illumination.

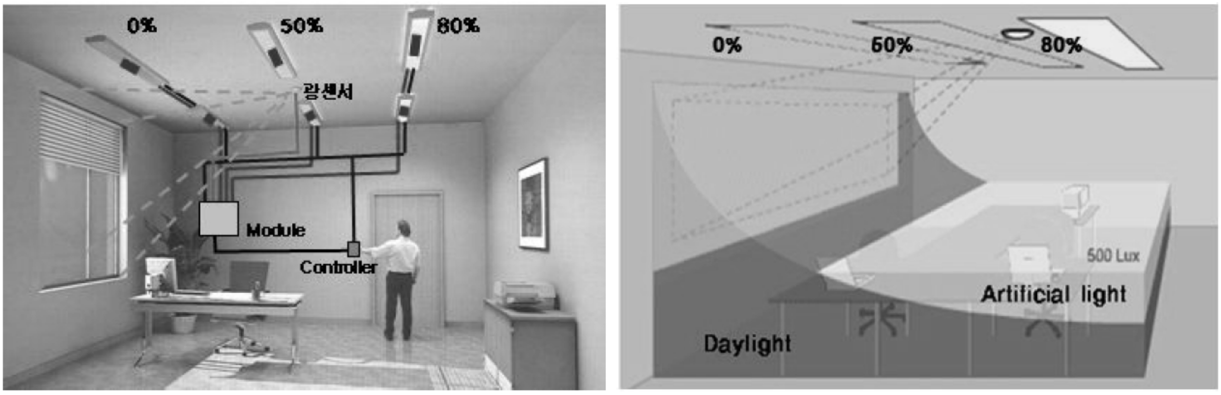

Figure 2. The concept of energy saving lighting control system (Yum, 2013)

3. Design Structure of the Smart Lighting

3.1 Factors affecting lighting in office

Chapter 2 above examined various factors that affect lighting environments. The following section divides these factors to physical and social factors, restructures them, and grasps their attributes.

Table 2. Factors affecting office lighting preference

Physical factor	Direct factor (lighting source)	Artificial light
		• Illumination, luminance
		• Color temperature, color rendering
		• Light distribution, type of the lighting
		• Glare
		Natural light
		• Daylight (Nearly buildings, direction of the window)
		• Blind
	Indirect factor (Indoor environment)	• Indoor structure
		• Reflectance of the interior finishing materials
		• Obstacle (Furniture, partition)
		• Location and direction of the desk
Social factor		• Purpose of space
		• Working method
		• Use pattern

Direct factors among physical factors mean a light source that brightens up a space. In this case, it is possible to adjust or manipulate lighting according to one's intention. Exceptionally, since it is impossible to control daylight diffusion, the light that reaches a space is controlled by means of blinds. Indirect factors mean environmental elements that form an indoor space. These affect the process that light diffusion from a light source reaches an object. Unlike direct factors, it is not easy to control lighting environments and a number of variables are involved. Thus, it is difficult to predict and configure every aspect as complex events occur. Finally, social factors are a basis to evaluate light in a certain space. These are to determine whether light is appropriate for the goals and uses of a space and what attributes should be adjusted to what extent. The relations between physical factors (direct and indirect factors) and social factors are as follows: The level of light in a space is determined in consideration of the space objectives and optimal environments (social factors) and lighting (direct factor) is turned on accordingly. Light diffusion is affected by various indoor obstacles and reflectors (indirect factors) before reaching the final surface. Various elements from those that can be adjusted and those that cannot may affect this process, and thus it is difficult to consider causality of such elements in creating work environments. Besides, the difference from intended lighting environments might be significant. Thus, the relation between space and light needs to be viewed as correlated rather than cause-and-effect. To create smart lighting environments, the optimal working environment should be tracked back based on the conditions of light that finally reaches an occupant (cf, illumination, color temperature, etc.).

3.2 Conceptual model of smart lighting

The process that light diffusion from a light source meets obstacles such as walls and partitions may involve reflection and refraction. Since light is affected by surroundings, designed light speed and luminous intensity might be different from those of actual luminance and illumination on the workspace. All these aspects are considered when lighting for a building is designed, but restructuring or rearranging of the office space thereafter is likely to involve further expenses and inconvenience, which makes it less practical to reflect such changes every time and maintain lighting accordingly. Unlike one-way manual lighting conditions were a unilateral order is issued and followed, smart lighting can be of cyclical structure and thus utilized as an alternative to such problems. In reflection of these features, a cyclic model of smart lighting is designed as illustrated in Figure 3. Since smart lighting makes it possible to measure the intensity and amount of light that reaches a workspace and to provide constant feedbacks to a light source, structural changes in the office can be reflected in lighting configuration.

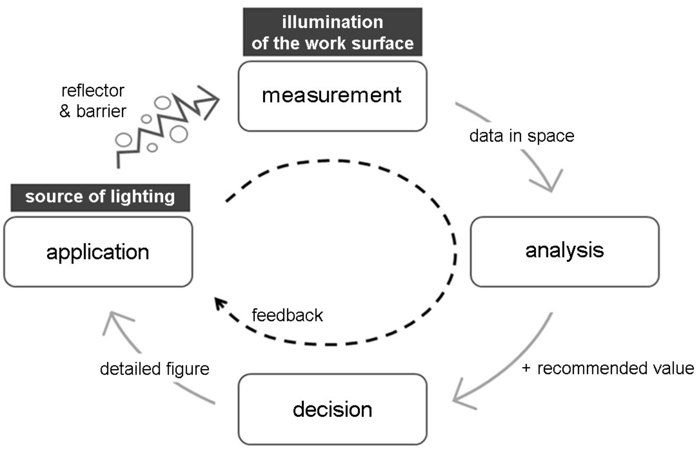

Figure 3. Circular flow of the smart lighting system

Illumination, which is an index of lighting environment, is an absolute and accurate value of physical measurement, but the brightness that an occupant actually feels might be different depending on the environment factors such as the partition structure and computer screen. In other words, the illumination that an occupant feels is not absolute but relative, and thus it is necessary to narrow the gap between the recommended values and those of actual lighting environments in the repeated cyclic process of smart lighting feedbacks and relevant events.

3.3 The structure of the smart lighting process

Smart lighting connects various devices and technologies to form an integrated system. The forms may be varied depending on goals and types of an office space. Hence, correlations among these factors are defined with the specific steps established in order to apply and practically utilize different forms of smart lighting structures as illustrated below:

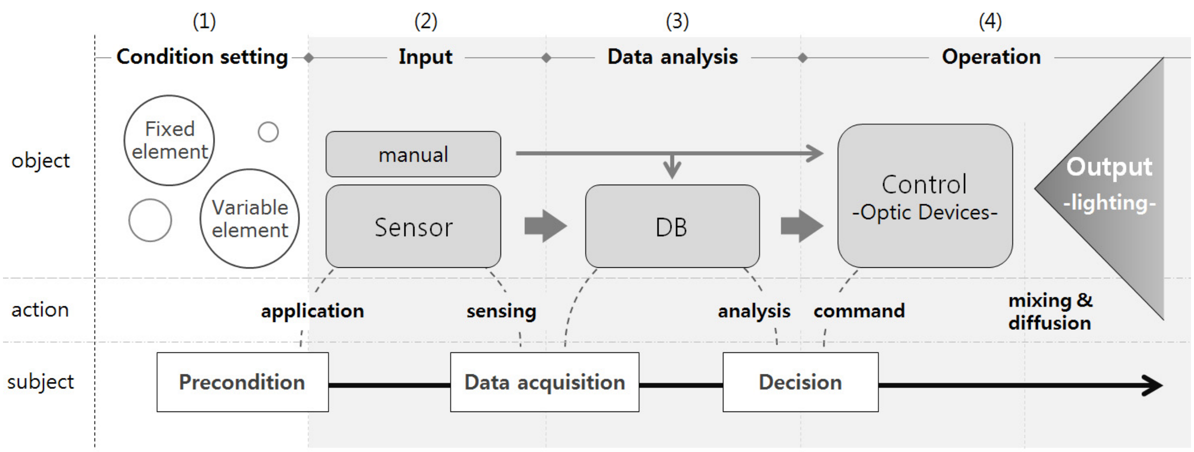

Figure 4. The structure of smart lighting process

Data of the space is collected through sensors installed in the office. In this case, WSN (wireless sensor network) is used to control the process, and AI methods are applied to maximize the effect. Once the situation of the site that involves many variables and uncertainty is grasped, a decision making process is implemented based on the system conditions and standards. In examination of the process, lighting environments suitable for the space objective and use are determined as a precondition (1), and the illumination and color temperature of that workspace are measured by means of sensors installed to collect space data (2). Collected data is accumulated in the database through the network, and the data sets are expanded through sensor convergence and analysis. Valid data is then extracted, and complicated events and conditions are processed in the order through a decision tree. (3). Individual raw data sets that were originally not significant are processed based on probabilities and statistics, through which the certainty of information is enhanced. The resulting values are applied to lighting, etc. (4). Lighting, etc. go through mixing and diffusion to realize light conditions that correspond to the calculated values with the light source adjusted and diffused outward.

3.3.1 Information for condition setting

To establish smart lighting, standard values and conditions for the system need to be established as a prerequisite. To this end, essential data for lighting environment creation and whether it is recognizable need to be taken into account. Hence, input elements significant for adjustment of office lighting environments are to be extracted and classified to variable elements and fixed elements.

Table 3. Condition setting element of the lighting system

(a) Variable element	Illumination, color temperature
	Movement, movement route, whether using or not, time of stay
(b) Fixed element	Suitable illumination & color temperature for the use of space
	Work type (VDT, detail work, production work, etc.)

Variable elements indicate information of lighting status that constantly changes on the surface of workspace, and the lighting conditions such as illumination and color temperature as well as occupants' actual use of space including his movement and work patterns are measured as direct information. In contrast, fixed elements are the basis for application of the optimized lighting environment to the given space. Recommended illumination and color temperature values are designated according to the type of space, and other types of information that would be little varied or hard to recognize are to be entered in advance. Recommended levels of illumination and color temperature may be different depending on the use, purpose, and type of space, and so is the type of lighting. However, context information is hard to recognize by means of sensors, and the error range is wide unless the data accuracy is secured. Thus, this type of information is set up manually.

3.3.2 Input type

In the process of entering data and commands into the system, data may be generated and entered automatically through sensors or manually manipulated directly by the user. According to Rebekah (2003), a user prefers the default settings before recognizing a problem of lighting. He also added that automated lighting makes it easy to grasp others' presence in the space and is useful for creating different environments depending on the number of occupants. In contrast, when tasks are to be implemented without automated lighting, users would feel inconvenient at times, and they would desire direct control of lighting. Users preferred setting automated lighting as the default and adding manual lighting control. The primary goal of smart lighting system is to remove the inconvenience for an occupant to manipulate lighting fixtures manually every time by using sensors and automatic recognition functions, but complete automation might be more inconvenient in constantly changing environments such as office space. In addition, whether a user can choose to control manually even if he does not do that way often makes

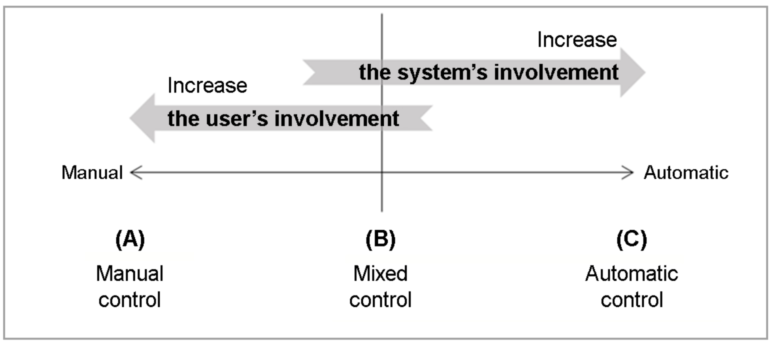

Figure 5. Degree of manual control

significant difference. Figure 5 illustrates this and classifies manipulations to manual, mixed, and automatic manipulations.

One of the most outstanding features of automatic lighting is to create optimal environments with no need for an occupant to pay constant attention to the working environment.

Since light changes natually and causes no hindrance to the occpuant's concentration, this setting contributes to consistent work process. However, it is the central controlling system that makes such decisions, and manipulation based on one individual's decision making is limited. Mixed manipulation means to be able to select either automated lighting or manual manipulation based on one's own decision making. This is advantageous when a workplace involves various situations and contexts which are hard to be grasped, and the variation depending on one's abilities and preferences also can be reflected. As data manually processed is accumulated in a system, it may be considered as a basis for decisino making.

3.3.3 Analysis

When an event occurs, there are two ways for a system to recognize it and judge if that is significant and analyze it. The first way is to present specific conditions directly and make decisions based on whether the conditions are satisfied, which is comparatively simple. The causality between an event and actions is clear, and this is useful especially when clear standards and conditions are applied. For instance, when the event is 'the illumination in workspace A is 350lx', there may be following conditions: (Condition 1) the illumination in workspace A is ranged within +/- 50lx from the standard 600lx'; (Condition 2) 'Light changes are gradual at the speed of 5 (%/s) so that the worker cannot recognize them. The resulting action is, 'the illumination of lighting in workspace A increases as much as 200lx at the speed of 5 (%/s)'. As an event is recognized as above, an action is taken to meet the conditions. The second way is to meet the expected values by adding accumulated data. This increases the probabilities of rational judgment, and a decision tree may be utilized to illustrate it. Through constant learning, factors that are closely linked to an event and standards for judgment are reflected, and expected effects are determined in consideration of all these factors. As data is accumulated, more various situations of a user can be taken into account. Since it is possible to learn not only data that is automatically sensed but also information manually processed, patterns, preferences, behaviors, and characteristics of an occupant who uses the office can be reflected to adjust the lighting status accordingly. As a result, the accuracy of decision making is enhanced, and the result becomes closer to the user's intent and purpose.

3.3.4 Application

The whole process from decision making to actual representation of light involves internal mechanical processing for the proper lighting environment. Once a command is issued for lighting by either the system or direct manipulation, the driving device is initiated with energy transferred to LED. By means of various controlling devices, LED lamps go through mixing and diffusion alternately, emitting light through optical devices. The measurements of illumination and color temperature can be adjustable directly while lighting elements such as uniformity ratio of illumination and glare can be adjusted through different lighting methods and installations.

4. Case Study

The case of Citigroup Centre EMEA in London, which installed Philips LED lighting system, is illustrated below. This building replaced the existing one with LED lightings with dimming functions and established a new control system. Since one third of each floor in that building was exposed to intense natural light, the system control was necessary to balance the natural light and artificial light in order to reduce energy consumption and maintain the designed illumination level.

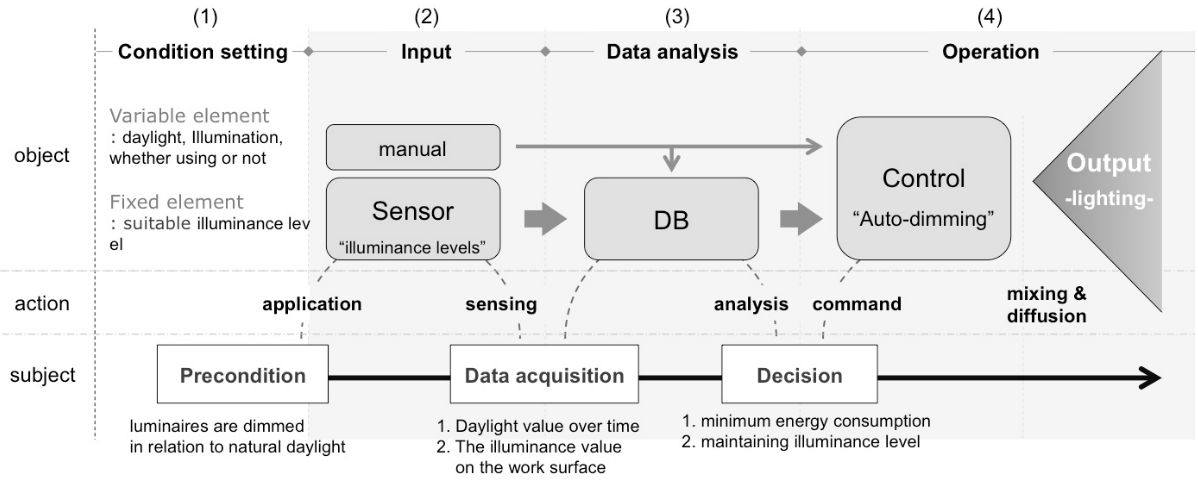

Figure 6. Smart lighting of citi-group building

A system was established to save lighting energy, which was estimated to account for 20 to 25% of the entire energy consumption in that building and to provide a high level of lighting to workers. As a result, it became possible to adjust lighting according to the workers' preferences in the right position by applying the dimming functions. Energy was saved as much as 36% by applying the lighting system in utilization of daylight.

5. Conclusion

This study structuralizes the general process of creating office lighting environments. To this end, various factors that might affect lighting environments were examined, and they were classified to physical factors - direct factors and indirect factors - and social factors. The relations among the factors were also analyzed.

Illustrated is the process of exchanging feedbacks in recognition of data that is generated while the generated light is delivered. This model of cyclic conceptualization can be utilized to draw a big picture of the system and establish it. Finally, the action process of smart lighting system is structuralized to the four steps: Condition setting - Input - Analysis - Operation in order. The specific issues in each step were further classified based on the Object, Action, and Subject. In this manner, created was a frame that can apply various forms of smart lighting for various purposes, which can be utilized to explain and structuralize events in lighting environments that involve complex causalities due to multiple variables.

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