Article

Sensory Perception Mechanism for Preparing the Combinations of Stimuli Operation in the Architectural Experience

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Abstract: Sensory stimuli in an architectural space play an important role in the human perception of the indoor environment, no matter whether they are static or dynamic, isolated, or combined. By enhancing some perceptions in the sensory stimuli, the overall perceptions of an architectural space can be improved, especially for an intelligent architectural space. As yet, there are few studies reported about the sensory perception mechanism for the sensory stimuli operation in the architectural experience. In this research, a wooden micro building was prepared for the study of the sensitivity level of participants to various sensory stimuli in the same and in different sensory domains. Participants’ visual, auditory, olfactory, tactile and kinaesthesia perceptions were discussed statistically in terms of the sensitivity level. Based on the study, the effect of a single dynamic sensory stimulus (a dynamically coloured light) on the participants’ perception was studied in a paper architectural model from two aspects including preference and emotion. The dynamically coloured light was discussed statistically in terms of the level of preference. The study showed that there are significant differences among participants’ levels of sensitivity to the different sensory domains and to the different sensory stimuli. In particular, the sensitivity level to the stimulus that is the colour of a space is the highest of all stimuli. As a single changing sensory stimulus, a dynamically coloured light can lead to significant mood fluctuations and changes in the preference level. In particular, yellow is the favourite colour of light. The object of this study is expected to provide a theoretical foundation that is related to sensory choice, sensory perception enhancement and the combination forms of sensory perceptions. Based on the theoretical foundation, the perception design of overlapped multi-sensory stimuli and a single dynamic stimulus can be conducted to improve the quality of the indoor environment of normal and intelligent multi-sensory architecture.

Keywords: multi-sensory intelligent architecture; sensory stimulus; perception enhancement; sensitivity

1. Introduction

With the rapid development of architectural technology, multi-sensory architecture emerges as the demand for new architectural functions grows. This prevailing conception of multi-sensory architecture has been largely informed by phenomenology as a field of multi-sensory experience since the 1990s [1]. Finnish architect Juhani Pallasmaa (2005) states that “experiencing architecture is multi-sensory; qualities of space, matter and scale are measured together by the eye, ear, nose, skin, tongue, skeleton and muscle”. However, architecture has mainly been experienced through the visual sense historically [2,3]. Some studies argued for multi-sensory architecture to criticise architecture based on visual images and emphasise the importance of the other senses in architectural experiences [4–10]. Some studies offered a far-reaching and more prospective multi-sensory approach toward the built environment [11]. Some studies explored connections between the multi-sensory space
and the emotional experience and pointed out that the interactive connections between the body and environmental stimuli are substantial elements for generating the emotional experience that improves the quality of an interior experience [2,12]. The environmental stimuli provide a multi-sensory space and generate various types of emotional experiences [13,14]. The technical support of multi-sensory architecture is provided by the development of algorithmic design, 3D-printed, interactive projection, and other technologies, thus new sensory perceptions and new aesthetics can be built by the combination of architecture and technologies [15–20]. For example, the XenoCells project uses a cell division algorithm that can be applied in varying resolutions to vastly different effect-achieving 3D-printed forms that range from sharp crystalline structures to organic folds reminiscent of internal organs. Accordingly, through simulating biological or other processes, deep data is being embraced by human sensibility to sculpt new cognition. By algorithmic design, novel aesthetics which reveal and materialise forces (friction, fluid dynamics and the like) that are normally hidden in the human perception can be used in the expression of architectural images to add more emotions to people [15]. Furthermore, for the Sensory Playscape and Sensory Surface prototypes related to the enabling technologies, interactivity with the textile surfaces is enabled through the use of depth-mapping data from a Microsoft Kinect, providing a valuable separation between the hardware and the media for interaction. A contouring algorithm is utilised to measure touch and pressure with any configuration of flat, contoured and layered geometries. Location and depth of touch are identified and tracked, subsequently triggering the transformation of visuals projected onto the textiles [21].

“Intelligent architecture” was used to describe buildings where microprocessor-based technologies were used in order to improve the buildings’ efficiency [22]. The intelligent architecture was founded on the basis of how the human mind perceives and interacts with the material world [23]. Accordingly, intelligent architecture itself has a close relationship with multi-sensory technologies. Using the senses can affect the user experience of intelligent building design, and an intelligent building can bring more diversified sensory perceptions for people than that of normal architecture [24]. For example, the iPad intelligent home can act as a communicative device to change people’s living styles. In this architectural space, the sensory perception and the emotion can be controlled or influenced by the sensory stimuli of the indoor environment to some extent.

Perception is formed through the seamless integration of initially segregated data regarding internal and external, social and non-social stimuli [21]. There are many studies about sensory perceptions, including decision-making, mental imagery, perception type, perception effect and so on, involving sociology, philosophy, psychology, physiology and neuroscience [25–28]. Some of the studies are related to the indoor environment, such as the perceptions of the temperature, the humidity, the air velocity, the noise, the air quality, the illuminance and other things [29–33].

There are some studies about the relationship between architectural space and sensory perception and the reason why the sensory perceptions of the architectural space can influence human behaviour [2–12]. Based on the phenomenology of architecture, a place exists because human sensation exists. The world of perception, or in other words the world which is revealed to us by our senses and in everyday life, seems at first sight to be the one we know best of all [34]. Sensory perceptions can be seen as the feedback of various sensory stimuli, such as light, colour, shape, volumetric geometry, and so on, then the feedback is integrated to form the whole architectural space image [35]. Conversely, the space can influence human sensation, and this influence may create a cascading effect because behaviour is believed to be a reflection of a complex and hierarchical interaction of multiple systems within the dynamic systems theory (DST) [36]. There is a relationship between the stimulus, perception and behaviour in an architectural space [37]. The concept of “perception intervention” about how space influences human sensation was proposed, and the interventions may not enhance the behaviour if efforts are not made to enhance the individuals’ awareness of their environment [24,38]. The appropriate design factors are necessary to enhance a certain perception factor [39]. In addition, the perception intervention
has a close association with enabling technologies. Through the utilisation of micro-location enabling technologies, user experience can be enhanced in a smart building [40].

Perception intervention and perception enhancement can be considered a tool to improve the quality of the indoor environment [12]. By reducing negative perception or enhancing the positive perception, the architectural perception design may enable intelligent and multi-sensory architecture to become more efficient and more accurate [41,42]. Nevertheless, as yet, there are few studies reported about the perception mechanism for the sensory stimuli operation in the architectural experience.

Senses are interrelated and inseparable, and the mutual influence of each perception element constitutes the entire experience of architectural perception [23]. Although the process of forming the perception is fairly complicated, the architectural perception design still can follow some principles. As long as these sensory stimuli are “in the right direction” according to the notion of congruency in the multi-sensory experience [43], these sensory stimuli can work together to enhance the perception. For example, an apple flavour and a green wall in an architectural space can work together to enhance each other. If alerting music is combined with a relaxing scent, shoppers may end up confused. Except for this, the notion of superadditivity means that weak uni-sensory impressions can combine to deliver a multi-sensory experience much richer than the sum of its parts [44]. The notion of congruency and superadditivity provide technical support for perception enhancement.

Based on the DST, people only receive, process and respond to the continuous and dynamic sensory stimuli in an interactive way, therefore “our living communication with the world” can be built [45]. People need the interactive process to build and enhance sensory perceptions in order to communicate with and understand the world [10,12]. People also need the interactive process to improve many kinds of abilities in multi-sensory intelligent architecture [21,24]. Accordingly, this interactive method of communication is a challenge that intelligent architecture must deal with. The adaptive intervention that brings interactive, continuous and dynamic sensory stimuli into architecture is a pivotal point.

Materiality, as an environmental stimulus, can enhance the spatial experience by engaging the body [2]. This means that materials can provide interior environments and directly stimulate sensory experience [46]. Sensual factors such as “material connection” involve texture, light, shadow, colour, temperature, sound, smell and other things, which relate to the arousal of people’s sensory perceptions [47]. The contemporary context for the perception of architectural space is related to the sensory (bodily senses, bodily movements) and the emotions (feeling, memory) [2]. There are some studies about sensory perception and emotions originating from an architectural space. For example, cross-modal effects of sound and illuminance were investigated in an indoor environmental chamber, and the perceptions were assessed using an 11-point numeric scale. One of the findings was that the illuminance conditions can not affect acoustic perception [29]. Visual, tactile, olfactory and auditory perceptions were all investigated in a plaster room and a wooden room, as well as emotions. The participants were asked to select a score (1–7 or 1–5) between a couple of adjectives about the perceptions to express their evaluation. This study tried to test whether the olfactory and auditory modalities would significantly contribute to a more comprehensive perception [48]. The material, colour, shape and other factors of some architectural spaces were evaluated by a seven-point Likert scale to test their effects on the clear perceptions of the architectural space [49]. Architectural colour harmony was studied and a seven-grade Likert scale was adopted for the questionnaire, with answers ranging from 1 for least preferred (disharmony) to 7 for favourite (harmony) [50]. The influence of air temperature on a participants’ mood was investigated, and the participants were asked to mark with a cross a number (from 0 to 100) on the scales evaluated [37]. In general, there are many perception studies about one or several normal sensory stimuli, but comprehensive studies about all sensory domains in an architectural space are rarely reported. In addition, the studies of the perceptions originating from the dynamic stimuli of an architectural space are rarely reported too, although there are many other studies about the dynamic stimuli. These studies are usually related to disease research, such as autism,
dyslexia, schizophrenia and so on [21,51–53]. For example, the dynamic face (neutral-to-happy or neutral-to-angry) and dynamic flower (closed-to-open, i.e., blooming) stimuli were arranged in a study of autism spectrum disorder [34]. Accordingly, it is necessary to study the sensory perceptions systematically, particularly the sensory perceptions of the dynamic stimuli. Furthermore, emotion is important in the study because the contemporary context for the perception of architectural space is related to the senses and emotions [2].

Human perception has long been a critical subject of design thinking. Spatial perception is multimodal and fundamentally bound to the body, which is not a mere receptor of sensory stimuli but an active agent engaged with the perceivable environment. Although the visual approach may provide a practical means to represent and communicate ideas, a design process heavily driven by visuality can exhibit weaknesses undermining certain aspects of spatial experience despite the complexity [35,56]. Accordingly, it is necessary to study the problems of the sensory perception design of an architectural space systematically. However, there are few systematic studies about this, although there are many other studies about product perception design. In the existing research on architectural perception, much of the research is usually related to sensory perceptions such as colour and shape [57–61], just like the studies about the product perception design, and is conducted through various subjective evaluations by pictures, models and real-size rooms [29,48–54,57–61].

In an architectural space, although senses are interrelated and inseparable, and the mutual influence of each perception element constitutes the entire experience [23], the selection of the sensory stimuli is the first step in the perception design. Furthermore, the notes of superadditivity and congruency as the theoretical foundation for the perception design have a direct relationship with the selection of the sensory stimuli. Only based on the study of the effect of every type of stimuli corresponding to the related perception domain on people can a further study of the combinations of the stimuli operation be conducted. Accordingly, this paper takes efforts to clarify a part of the sensory perception mechanism in a systematic study involving basic sensory perceptions, the perception domains and a dynamic stimulus selected. This study aims to discuss which sensory stimulus influences or does not influence participants and identify which sensory domain it belongs to. Furthermore, based on this study, a single sensory stimulus that easily influenced participants was used to study the effect of its dynamic changes on the participants’ perception. The first object of this study is expected to contribute to optimising the selection of the sensory stimuli and the matching and coordination of them to achieve the purpose of the perception enhancement. This object is based on the study results about the effect of every type of stimuli on people in this paper. The second object of this study is expected to provide a theoretical foundation for the perception design of multi-sensory stimuli and a single dynamic stimulus adapted to an interactive method to improve the quality of the indoor environment of normal and multi-sensory intelligent architecture. The former part of the second object is based on the study results about the effect of every perception domain on people in this paper because multi-sensory stimuli mean the stimuli in the multi-perception domains. The latter part of the second object is based on the study results about the effect of the dynamic stimulus selected on people in this paper. In summary, this study was set up to prepare for the further study of the combinations of stimuli operation in the architectural experience.

Specifically, it was tested whether: (1) In a wooden micro-architectural space there are comparative sensitive domains in the five sensory domains related to vision, tactile, auditory, olfactory and kinaesthesia senses, and there are obvious differences in sensitivity among the various sensory stimuli in the same and different sensory domains; (2) There are obvious differences among the effects due to the dynamic changes of a single stimulus (a dynamically coloured light) on participants’ perceptions and their emotions.

It was expected that: (1) There would be some comparative sensitive domains in the five sensory domains, and the visual sensory domain would be the most sensitive of all; (2) There would be obvious differences in sensitivity among the various sensory stimuli in the same and different sensory domains. The colour and the volumetric geometries of the
wall, ceiling and furniture would be more sensitive than other stimuli; (3) There would be obvious differences among the effects due to the dynamic changes of a single stimulus (a dynamically coloured light) on participants’ perception and their emotions. Warm colours would be preferable to others.

2. Methods

Some sensory stimuli may play a great role in people’s feelings, some of them may play a great role in people’s behaviour, some of them may play a great role in people’s self-understanding [62]. Consequently, it is necessary to study the perception mechanism for the sensory stimuli’ operation in the spatial experience, no matter if the sensory stimuli are in different sensory domains or in the same sensory domain. Accordingly, a specific architectural space with multi-sensory stimuli was provided for the systematic sensory perception study. All of these stimuli should be positive or neutral because of the notion of congruency, which is helpful for the comparison of sensitivity to the sensory stimuli avoiding some conflicts. The comparison can be conducted through subjective evaluation. The study of sensitivity to the sensory stimuli may contribute to analysing the effect of every sensory stimulus as a perception intervention or a perception enhancement. Based on the study of sensitivity, a continuous and dynamic sensory stimulus adapted to the interactive method of communication for intelligent architecture can be selected. Accordingly, a unique stimulus and an indoor environment need to be provided in the study. Because the contemporary context for the perception of architectural space is related to the sensory and the emotions, the effect of the unique stimulus can be studied through the subjective evaluation of participants’ preference level and in-depth interviews about their emotions.

2.1. Sensory Stimuli in the Same and Different Sensory Domains

Based on the previous studies [48,63–66], a small square space may be adapted to test the vision, tactile, auditory olfactory and kinaesthesia senses to some extent and may be easy to concentrate all kinds of sensations together for a subjective test. Accordingly, a wooden micro building was built sized 2.2 m (l) × 2.0 m (w) × 2.3 m (h) to clarify the mechanism of the process of how the participants respond to different sensory stimuli in different sensory domains with different sensitivities. In this wooden micro building, participants can experience encompassing contact between the body and the architectural space. There was some basic furniture and ornaments in this building. Some of them were upholstered and shaped with curved volumetric geometries. Some had unique smells and music was also provided in this building (Figures 1–4). Generally, these sensory factors included visual stimuli (the colours, the decorative pattern, the individual ornaments, the volumetric geometry), auditory stimuli (music), olfactory stimuli (smell), tactile stimuli (the texture of the wall, the texture of the furniture), kinaesthesia stimuli (elasticity) (Figure 5). This building provided an ordinary living environment but it was very small. The stimuli in it were concentrated and can be easily perceived by participants to some extent. Additionally, this experiment may be relevant to other various factors, such as culture, religion, economy, and politics [67]. For the sake of the study object, the research is confined to Chinese culture to avoid the impacts of different cultures.

The survey questions used in this study consisted of general questions for participants and self-reported questions for spatial perception [63]. The general questions contained information about the participants such as gender and age [63,68] and were used to analyse the demographic characteristics and spatial perception ability of the participants. The health conditions were prescreened in order to satisfy the general standards for participants. The questions for the spatial perception used in the survey were presented in Table 1. The organisation of the spatial perception questions for the main survey was established logically in order to interpret the relationship between sensory stimuli and sensory perceptions appropriately. The questions regarding the sensory stimuli were divided into five categories: visual sense, auditory sense, olfactory sense, tactile sense and kinaesthesia.
sense. Through the experience in the reality space, the levels of sensitivities to sensory stimuli were evaluated.

Figure 1. The external of the wooden micro architecture.

Figure 2. Micro architecture plan. (1: entrance, 2: bed, 3: cabinet, 4: desk, 5: bathroom, 6: storeroom).

Figure 3. One occupant in the wooden micro architecture.

Figure 4. The internal of the wooden micro architecture.
Figure 4. The internal of the wooden micro architecture.

Figure 5. The sensory stimuli and sensory perceptions in different sensory domains.

Table 1. Contents of questionnaire for the level of sensitivity to the sensory stimuli.

<table>
<thead>
<tr>
<th>Number</th>
<th>Question Content</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Do you perceive easily the colour of the wall, ceiling and furniture?</td>
<td>visual stimuli</td>
</tr>
<tr>
<td>A2</td>
<td>Do you perceive easily the decorative pattern on the wall, ceiling and furniture?</td>
<td>visual stimuli</td>
</tr>
<tr>
<td>A3</td>
<td>Do you perceive easily the individual ornaments?</td>
<td>visual stimuli</td>
</tr>
<tr>
<td>A4</td>
<td>Do you perceive easily the volumetric geometries of the wall, ceiling and furniture?</td>
<td>visual stimuli</td>
</tr>
<tr>
<td>A5</td>
<td>Do you perceive easily the music inside?</td>
<td>auditory stimuli</td>
</tr>
<tr>
<td>A6</td>
<td>Do you perceive easily the smell inside?</td>
<td>olfactory stimuli</td>
</tr>
<tr>
<td>A7</td>
<td>Do you perceive easily the texture of the wall?</td>
<td>tactile stimuli</td>
</tr>
<tr>
<td>A8</td>
<td>Do you perceive easily the texture of the furniture?</td>
<td>tactile stimuli</td>
</tr>
<tr>
<td>A9</td>
<td>Do you perceive easily the resilient floor?</td>
<td>kinaesthesia stimuli</td>
</tr>
</tbody>
</table>

A five-point Likert scale was used to answer all questions from strongly disagree (−2 points) to strongly agree (+2 points) as described in Table 2.

Table 2. Likert voting scale for questionnaires.

<table>
<thead>
<tr>
<th>Answer</th>
<th>Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly agree</td>
<td>2</td>
</tr>
<tr>
<td>Slightly agree</td>
<td>1</td>
</tr>
<tr>
<td>Neither agree nor disagree</td>
<td>0</td>
</tr>
<tr>
<td>Slightly disagree</td>
<td>−1</td>
</tr>
<tr>
<td>Strongly disagree</td>
<td>−2</td>
</tr>
</tbody>
</table>

Seventy-two subjects that consisted of college-aged male and female students were asked to participate in the experiment on campus. Their age varied from a minimum age of 20 to a maximum age of 22 years, with a mean age of 20.5 years. That the participants are only young adults is at the request of the experiment, which needs their interest.
and their sensory ability. On the one hand, some studies indicated that the millennial generation in their 20s and 30s pursue sensory luxury in small living spaces in which both leisure and rest can be enjoyed [64]. On the other hand, some studies indicated that younger adults (mean age 31) showed greater overall levels of temporal and occipital cortical activation than older adults for both auditory and visual stimuli [69]. Because this study involves auditory sensation and visual sensation, the young subjects who may be interested in the experiments related to a small living space are selected to avoid the influence of cognitive decline in ageing, just like the study about the sensory response to visual stimuli [70,71]. In addition, the participants in this paper are university students, who easily understand the experiment and are good at answering the questions correctly due to their well-educated backgrounds. All participants received a description of the experiment with brief instructions, by which they were introduced to the experimental activity. These participants had no related perception disease. The instructions have stated that all subjects should have a good rest and keep calm before the experiment in order to ensure that all subjects were energetic and had no severe emotional fluctuations.

They evaluated the five kinds of sensations by using the five-point numeric scale in a random order to avoid the influence of order in the test. During this survey, the participants navigated the space of the micro building during the 2 min period and perceived the sensory stimuli in it. The reason why a 2 min experiment time was selected is that the object of this experiment is to test the participants’ ability to perceive various sensory stimuli from the spatial components, and a short time is necessary to obtain an instant impression while avoiding the distraction of participants’ attention due to a relatively long time. Because of this, 2 min as the noise exposure experiment time for auditory perception was adopted in some studies [71]. After the participants experienced the space, they answered the survey questions by filling out the questionnaire that corresponded to each spatial sensory stimulus from Number 1 to Number 9, as listed in Table 1. These questions evaluated the ability of each sensory stimulus to form perception, and the ability is associated with the participant’s sensitivity to various stimuli. After the experiment, the sixty participants’ acceptable responses were analysed including thirty females and thirty males.

2.2. A Single Dynamic Sensory Stimuli

A paper architectural model was built to make the second subjective test (Figure 6). The size of this building is 2 m (l) × 2 m (w) × 1 m (h). It has three rooms and a balcony with some basic furniture and ornaments. In this test, the colour of the light can be considered as a kind of intervention to enhance visual perception. Ten kinds of coloured lights spread into this building to test participants’ preferences and the feelings corresponding to every change in the colour of the light, including red, orange, yellow, chartreuse, green, cyan, blue, purple, purplish-red, and white.

![Figure 6](image_url)

**Figure 6.** Different colours of the coloured light in the architectural model.

The questions for the visual perception involving the preferences of ten kinds of colours of the light in the building applied in this survey are presented in Table 3. Through
the experience in the space, the level of preference for visual stimuli about the changing coloured light in the building is evaluated.

Table 3. Contents of questionnaire for the level of preference for the coloured light.

<table>
<thead>
<tr>
<th>Number</th>
<th>Question Content: Do You Prefer the Light in the Room?</th>
<th>Category</th>
<th>Sensory Stimulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>the red light</td>
<td>visual stimuli</td>
<td>colour light</td>
</tr>
<tr>
<td>B2</td>
<td>the orange light</td>
<td>visual stimuli</td>
<td>colour light</td>
</tr>
<tr>
<td>B3</td>
<td>the yellow light</td>
<td>visual stimuli</td>
<td>colour light</td>
</tr>
<tr>
<td>B4</td>
<td>the chartreuse light</td>
<td>visual stimuli</td>
<td>colour light</td>
</tr>
<tr>
<td>B5</td>
<td>the green light</td>
<td>visual stimuli</td>
<td>colour light</td>
</tr>
<tr>
<td>B6</td>
<td>the cyan light</td>
<td>visual stimuli</td>
<td>colour light</td>
</tr>
<tr>
<td>B7</td>
<td>the blue light</td>
<td>visual stimuli</td>
<td>colour light</td>
</tr>
<tr>
<td>B8</td>
<td>the purple light</td>
<td>visual stimuli</td>
<td>colour light</td>
</tr>
<tr>
<td>B9</td>
<td>the purplish-red light</td>
<td>visual stimuli</td>
<td>colour light</td>
</tr>
<tr>
<td>B10</td>
<td>the white light</td>
<td>visual stimuli</td>
<td>colour light</td>
</tr>
</tbody>
</table>

A five-point Likert scale was also used to answer all questions from strongly disagree (−2 points) to strongly agree (+2 points), as described in Table 2.

One hundred and seven subjects that consisted of college-aged male and female students were asked to participate in this experiment. All participants received a description of the experiment with brief instructions, by which they were introduced to the experimental activity. These participants had no visual perception disease. Their age varied from a minimum age of 18 to a maximum age of 23 years, with a mean age of 22.4 years. Before the experiment, all subjects were energetic and had no severe emotional fluctuations. During this survey, the participants observed the space for a 1 min period and perceived the coloured light in the architectural space at random. After the participants observed the space, they answered the survey questions by filling up the questionnaire corresponding to each colour of the light from Number 1 to Number 10, as listed in Table 3. These questions evaluated each participant’s preferences for every colour of the light. After the experiment, there were ninety acceptable participant responses which were analysed, including forty-five female and forty-five male responses. In addition, a question was prepared for an in-depth interview after the subjects had finished their visual sensation vote to improve the results of the study. The question (What do you feel when you perceive the colour light in the room?) is prepared for ten kinds of different coloured lights.

3. Results

3.1. Sensory Stimuli in Different Sensory Domains

The percentage of the participants in their ability to perceive various spatial sensory stimuli are described in Table 4. A total of 86.7% of participants answered that they could very easily perceive A1, 45.0% of participants answered that they could very easily perceive A8, 36.7% of participants answered that they could very easily perceive A9, 30.0% of participants answered that they could very easily perceive A3 and A5, 28.3% of participants answered that they could very easily perceive A6 and A7, and 26.7% of participants answered that they could very easily perceive A4.

The voting result was analysed using statistical tools, and is shown in Figure 7. All mean (M) and standard deviation (SD) of responses (A1–A9) for the spatial perception in the survey questions in Table 1 are presented below. A1 is the most sensitive object compared to the others (M = 1.72, SD = 0.87), followed by A3 (M = 1.12, SD = 0.81), then A8 (M = 0.70, SD = 1.31), A6 (M = 0.65, SD = 1.16), A5 (M = 0.61, SD = 1.28), A9 (M = 0.43, SD = 1.36), A4 (M = 0.40, SD = 1.09), A2 (M = 0.08, SD = 1.21) and A7 (M = −0.03, SD = 1.48).
nervousness and sadness, but some feelings may be negative, such as anxiety and romantic, but some feelings may be positive such as happiness, calmness, and heightened emotional experiences. People’s feelings are influenced by the continuous changes of the colour of the light as a kind of spatial visual intervention. The effects due to its dynamic changes on participants are analysed. The study above indicated that the participants have a comparatively high level of sensitivity to most of the stimuli in the visual domain, except A2.

### 3.2. Different Sensory Stimuli in the Same Sensory Domain

The statistical analysis results for each question about the visual sensory domain are presented in 2.1. A1 can be perceived more easily by participants (M = 1.72, SD = 0.87), followed by A3 (M = 1.12, SD = 0.81), then A4 (M = 0.40, SD = 1.09) and A2 (M = 0.08, SD = 1.21). In general, the participants have a comparatively high level of sensitivity to most of the stimuli in the visual domain, except A2.

### 3.2.2. Tactile Sensory Domain

The statistical analysis results for each question about the tactile sensory domain are presented in 2.1. A8 (M = 0.70, SD = 1.31) can be perceived more easily by participants than A7 (M = −0.03, SD = 1.48). The difference between these two sensitivities is enormous.

### 3.3. A Single Changing Sensory Stimuli

The study above indicated that the participants have a comparatively high level of sensitivity to the stimuli in the visual domain and the sensitivity level of A1 about the colour is the highest of all. In addition, the continuous and dynamic sensory stimuli need to be studied for a multi-sensory experience in an interactive way. Accordingly, a changing coloured light is taken to study as a single, continuous and dynamic sensory stimulus.

### Table 4. Participants’ ability to perceive sensory stimuli from the spatial components.

<table>
<thead>
<tr>
<th>Category</th>
<th>Number</th>
<th>Percentage/%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>−2</td>
<td>−1</td>
</tr>
<tr>
<td>visual stimuli</td>
<td>A1</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td>8.3</td>
</tr>
<tr>
<td></td>
<td>A3</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>A4</td>
<td>1.7</td>
</tr>
<tr>
<td>auditory stimuli</td>
<td>A5</td>
<td>5.0</td>
</tr>
<tr>
<td>olfactory stimuli</td>
<td>A6</td>
<td>5.0</td>
</tr>
<tr>
<td>tactile stimuli</td>
<td>A7</td>
<td>11.7</td>
</tr>
<tr>
<td>kinaesthesia stimuli</td>
<td>A8</td>
<td>3.3</td>
</tr>
<tr>
<td></td>
<td>A9</td>
<td>5.0</td>
</tr>
</tbody>
</table>

**Figure 7.** The sensitivity level of indoor sensory stimuli.
stimulus. The effects due to its dynamic changes on participants are analysed. This study is conducted from two aspects which are preferences and emotions because colour could influence people’s feelings differently; some feelings may be positive such as happiness, calm and romantic, but some feelings may be negative, such as anxiety, nervousness and sadness [65,72].

3.3.1. The Level of Preference

Through the emotional experiences in the model space, the level of preference for the colour of the light as a kind of spatial visual intervention was evaluated. The percentage of participants and their preferences for the colour of the light are listed in Table 5. A total of 80.0% of participants answered that they prefer B3 very much, 35.6% of them answered that they prefer B2 very much, 35.6% of them answered that they prefer B10 very much, 31.1% of them answered that they prefer B9 very much, and 24.4% of them answered that they prefer B6 very much.

<table>
<thead>
<tr>
<th>Number</th>
<th>Percentage/%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>−2</td>
</tr>
<tr>
<td>B1</td>
<td>64.4</td>
</tr>
<tr>
<td>B2</td>
<td>13.3</td>
</tr>
<tr>
<td>B3</td>
<td>1.1</td>
</tr>
<tr>
<td>B4</td>
<td>13.3</td>
</tr>
<tr>
<td>B5</td>
<td>24.4</td>
</tr>
<tr>
<td>B6</td>
<td>20.0</td>
</tr>
<tr>
<td>B7</td>
<td>8.9</td>
</tr>
<tr>
<td>B8</td>
<td>10.0</td>
</tr>
<tr>
<td>B9</td>
<td>1.1</td>
</tr>
<tr>
<td>B10</td>
<td>1.1</td>
</tr>
</tbody>
</table>

The voting result was analysed using statistical tools, and is shown in Figure 8. All mean (M) and standard deviation (SD) of responses (B1–B10) for the spatial perception in the survey questions in Table 3 are presented below. B3 is the most preferable colour (M = 1.66, SD = 0.78), followed by B10 (M = 0.73, SD = 1.31), then B9 (M = 0.70, SD = 1.06), B6 (M = 0.41, SD = 1.41) and B2 (M = 0.37, SD = 1.39). B8 (M = 0.27, SD = 1.04) and B7 (M = 0.17, SD = 1.17) have no apparent tendency. B4 (M = −0.52, SD = 1.07) and B5 (M = −0.57, SD = 1.30) have a lower preference level, and B1 (M = −1.32, SD = 1.12) has the lowest level.

Figure 8. The level of preference for the colour of light.
3.3.2. Emotion

Ten questions were prepared for the subjects after they had finished their visual sensation votes. The questions and measures about the participants’ emotions are shown in Table 6.

Table 6. Questions to investigate the feelings of people.

<table>
<thead>
<tr>
<th>Question: What Do You Feel When You Perceive the Coloured Light in the Room?</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>Majority (89.7%) felt anxiety and nervousness.</td>
</tr>
<tr>
<td>Orange</td>
<td>More than half (55.1%) felt romantic, happy and comfortable.</td>
</tr>
<tr>
<td>Yellow</td>
<td>Majority (77.6%) felt happy, calm and relaxed.</td>
</tr>
<tr>
<td>Chartreuse</td>
<td>Less than (49.5%) felt loneliness and fear, and less than half (45.8%) felt calm and cool.</td>
</tr>
<tr>
<td>Green</td>
<td>More than half (55.1%) felt anxious and sad.</td>
</tr>
<tr>
<td>Cyan</td>
<td>Majority (94.4%) felt cool, calm and relaxed.</td>
</tr>
<tr>
<td>Blue</td>
<td>Majority (73.8%) felt calm and cool.</td>
</tr>
<tr>
<td>Purple</td>
<td>Majority (75.7%) felt romantic.</td>
</tr>
<tr>
<td>Purplish-red</td>
<td>More than half (54.2%) felt happy and romantic.</td>
</tr>
<tr>
<td>White</td>
<td>Majority (96.3%) felt calm.</td>
</tr>
</tbody>
</table>

4. Discussion

4.1. Sensory Stimuli in Different Sensory Domains

Based on the result of the first experiment, the participants easily perceived more than half of the spatial stimuli. Through calculating the average of each percentage of the participants who selected 2, 1, 0, −1 and −2, the results can be obtained that, 35.6% of the participants perceived the various sensory stimuli very easily, 21.9% of the participants perceived them easily, 18.16% of the participants had no apparent tendency, 19.44% of the participants were not sensitive to these sensory stimuli, and 5.0% of the participants were not sensitive to these sensory stimuli very much. The percentage of sensitive participants and non-sensitive participants was 57.5% and 24.4%, respectively. Based on the above data, it is speculated that the participants’ sensitivity level to various stimuli has obvious differences, and there are some participants (21.7%) who are indeed non-sensitive to indoor sensory stimuli. Some studies have indicated that individual diversity appears to influence the tactile, auditory, and olfactory evaluation of the settings and highlighted the importance of considering multiple sensory modalities when investigating an interaction experience between wood–humans [48].

For different sensory domains, the level of visual domain sensitivity is the highest of all, and its average value arrives at 0.83. This is consistent with expectation (1). The olfactory domain A6 (M = 0.65, SD = 1.16) is slightly lower than the visual domain, followed by the auditory domain A5 (M = 0.61, SD = 1.28), then the kinaesthesia domain A9 (M = 0.43, SD = 1.36) and the tactile domain. Although A8 (M = 0.70, SD = 1.31) in the tactile domain is fairly high, A7 (M = −0.03, SD = 1.48) is relatively low, meaning that its average value only arrives at 0.34. The reason for the highest sensitivity level being the visual domain may be that people are used to obtaining the most information from visual senses directly and conveniently, and people access external information and recognise things through sensory organs, primarily visual functions [50]. The reason for the higher sensitivity of the olfactory domain and the auditory domain may also be their direct and convenient perception method, and ambient odours have repeatedly proven to be able to influence both mood and behaviour in people [73–76]. The olfactory and auditory modalities would significantly contribute to a more comprehensive perception and evaluation of the indoor environments [48]. The Kinaesthesia domain and the tactile domain have a close relationship with human behaviour and may not be perceived directly so their sensitivity levels are relatively low.
4.2. Different Sensory Stimuli in the Same Sensory Domain

The result of the experiment indicates that the sensitivity level of A1 (M = 1.72, SD = 0.87) is the highest of all, followed by A3, then A4 and A2. It is shown that the colour in an architectural space is significant from the aspect of perception. The result is consistent with expectation (2). However, the sensitivity level of A3 (M = 1.12, SD = 0.81) is fairly higher than that of A4. This result is not consistent with expectation (2). Some of the reasons for the above results may be that colour can be more easily perceived than the decorative pattern at the same distance, and the individual ornaments are used to attract attention usually, so they can be perceived easily too. Some studies also indicated that colour and light affect architectural space most significantly, and colour determines the sense of spaciousness, depth of perception, wayfinding, and other factors [77–79]. The sensitivity level of A8 is similar to A5 and A6, but A7 is quite low. One of the reasons may be that in a normal architectural space, participants have more opportunities to touch the furniture, but have fewer opportunities to touch the wall.

4.3. A Single Changing Sensory Stimulus

Through calculating the average of each percentage of the participants who selected 2, 1, 0, −1 and −2, the results can be obtained that 23.9% of the participants preferred the coloured light very much, 20.7% of the participants preferred some colours of the light, 21.7% of the participants had no apparent tendency, 18.0% of the participants disliked some colours of the light, and 15.78% of the participants disliked some colours of the light very much. The percentage of likes and dislikes was 44.6% and 33.8%, respectively. Based on the above data, it is speculated that a dynamic single stimulus would lead to significant changes in most of the participants’ preferences. This is consistent with expectation (3). Some studies have a similar result that architectural space can have a diverse emotional significance and impact on an individual’s emotional state [80].

Based on the result of the second experiment, B3 is the most preferable colour (M = 1.66, SD = 0.78), followed by B10 (M = 0.73, SD = 1.06), B6 (M = 0.41, SD = 1.41), B2 (M = 0.37, SD = 1.39), B8 (M = 0.27, SD = 1.04), B7 (M = 0.17, SD = 1.17), B4 (M = −0.52, SD = 1.07), B5 (M = −0.57, SD = 1.30) and B1 (M = −1.32, SD = 1.12). Not all warm colours are preferable, such as B1 and B4. This is not consistent with expectation (3). For the particular colour of the light, more than 80% of participants preferred B3, but only 20–40% of participants preferred another colour. The difference in these percentages is enormous. It is indicated that B3 is relatively important among B1–B10. Some studies indicate that many participants associated luminosity with yellow, both in the United States and in Europe [72]. Except for B3, B2 is a distinctive colour. For most colours of the light, the more participants that like them, the higher the level of the preference for them is. However, B2 is an exception. Although 35.6% of the participants liked B2 very much, its level of preference is only 0.37. One of the reasons for this may be that the differences in the perceptions of the orange light are great.

The result of the interview after the second experiment showed that B4 (M = −0.52, SD = 1.07), B5 (M = −0.57, SD = 1.30) and B1 (M = −1.32, SD = 1.12) can arouse various negative emotions, as well as the level of their preferences being relatively low. Some studies demonstrate a similar result. For example, especially pictures with red hue colour combinations have the lowest preference and harmony values [50]. B3 (M = 1.66, SD = 0.78), B9 (M = 0.70, SD = 1.06), B6 (M = 0.41, SD = 1.41) and B2 (M = 0.37, SD = 1.39) can arouse various positive emotions, as well as the level of their preference being relatively high. However, B10 is an exception. The preference level for B10 (M = 0.73, SD = 1.31) is relatively high, even though the emotion aroused by it is relatively weak. Some studies also indicate that white is the preferred colour in the Asian regions (Japan, Korea, Taiwan, and China) [81]. In general, the dynamically coloured light can lead to significant mood fluctuations. This is consistent with expectation (3).

In summary, all kinds of sensory stimuli of architectural space in the first experiment are overlapped and integrated to form the whole architectural space image. Based on
the notion of congruency and superadditivity, if the sensory domain and the sensory stimuli with higher sensitivity levels can obtain more attention, it may be beneficial to enhance the related perception to gain a better effect for improving the quality of the indoor environment. For the second experiment, because the preferences and emotions aroused by various colours of the light are different, the colour of the light can be selected to be used in the perception design for the indoor environment based on its features. With the continuous conversion of the colour of the light, the preferences and emotions of the participants changed rapidly and sensitively, as shown in the above experiment. It means that dynamically coloured light could play an important role in the interactive nature of perception design. The interactive process starts from a sensory stimulus or some stimuli to a behaviour and from the behaviour to a new sensory stimulus or some new stimuli, regarding time series and the causal relationship. In the design of intelligent building systems, various smart technologies should be combined with different interaction modes for different users, and the designers should pay attention to the characteristics of the different users, that is the interactive experience principle (IEP) of smart design in the intelligent building system (a “people-oriented” approach) [8]. If a sensory stimulus can obtain quick feedback and its effect on the participants is significant, this sensory stimulus is a favourable choice for interactive perception design. In this study, B2, B3, B6 and B9 can cause adequate emotions and higher preferences, and therefore could be selected for perception design to contribute to improving some human behaviours and the quality of an indoor environment.

5. Conclusions

This paper focused on the sensitivity level of participants to various sensory stimuli in the same and in the different sensory domains. Afterwards, the effect of a single dynamic sensory stimulus on the participants’ perception was studied, which was conducted from two aspects including preferences and emotions. The study shows that there are significant differences among participants’ levels of sensitivity to different sensory domains, and to the different sensory stimuli in the same or different sensory domains similarly. Different sensory domains and the different sensory stimuli in the same sensory domains are ranked, respectively, based on the experimental result regarding the sensitivity. The level of the visual domain sensitivity is the highest of all. In particular, the sensitivity level to the stimulus about the colour of the wall, ceiling and furniture is the highest of all stimuli in the visual domain. As a single changing sensory stimulus, a dynamically coloured light can lead to significant mood fluctuations and changes in preference. In particular, yellow is the favourite colour of light. The object of the study is expected to provide a theoretical foundation for the perception design of the overlapped multi-sensory stimuli and a single dynamic stimulus adapted to an interactive method to improve the quality of an indoor environment of normal and intelligent multi-sensory architecture.

Based on the study, it can be concluded that the sensory perception design is related to three problems, which are how to select the sensory stimuli, how to determine the enhancement method and how to match these sensory stimuli. The study may play a role in partly unravelling the three problems. The first experiment of this study matches mainly the first and the third problems, and the second experiment in this study mainly matches the second problem. Firstly, the sensory domain and the sensory stimuli can be selected depending on their level of sensibility and their feature. For example, a yellow light that has a high level of sensibility and belongs to a highly sensitive sensory domain is an appropriate choice to improve the quality of the indoor environment based on its high efficiency and to lighten the mood based on its feature. Secondly, the enhancement method can be determined depending on the adaptability of a sensory stimulus. For example, visual perception can be enhanced by static or dynamically coloured light. Thirdly, based on the notion of congruency and superadditivity, the sensory stimuli with a high sensitivity level can be matched together to enhance the sensory perception or to compensate for the weak sensory perception that existed. For example, bright curtains or walls (the visual
sensory domain with the first-highest sensitivity) and the scent of flowers (the olfactory sensory domain with the second-highest sensitivity) can cheer up a dull room (Figure 9).

This study was set up to prepare for the study of combinations of stimuli. The first work before the study of combinations of stimuli is the selection of the sensory stimuli. Based on this paper, some stimuli and sensory domains with high-level sensitivity and a high ability to arouse human emotion are obtained to contribute to further study. In the future, how and which stimuli work together and reinforce each other will be studied. The stimuli with a high level of sensitivity in all kinds of combination modes in an architectural space will be studied through subjective evaluation and other methods based on the note of superadditivity and congruency.

Considering the close relationship between the intelligent buildings and the design of multi-sensory perception, it would be interesting as a next investigation to deepen the results described in the present study. On the one hand, the goal of housing projects is to provide satisfactory environments for users, but humans are embedded in and constrained by their environments [68,82]. Based on the phenomenology of architecture, DST, and the notion of congruency and superadditivity, a limited living or working space can be improved by means of the enhancement of the sensory perceptions in the multi-sensory architecture. Today, there are many people who have to live and work in small and poor architectural spaces due to their low incomes. Sometimes these spaces are not humanised, and people have no choice but to accept them. To make these spaces comfortable is a great challenge. Multi-sensory micro architecture can play an instrumental role. Depending on the enhancement of the sensory perceptions, people may change a very small and poor space into a better one [83–87]. Under the situation of affordable architectural space shortage, it may be a good way to unravel part of the problem. In the future, some studies may contribute to arriving at this target. On the basis of the study, the various scale architectural spaces with a high level of sensitivity stimuli in all kinds of combination

Figure 9. Sensory perception reinforcement process.
modes can be studied through subjective evaluation and other methods based on the note of superadditivity and congruency. On the other hand, based on the phenomenology of architecture, DST, and the notion of congruency and superadditivity, the upscale of intelligent multi-sensory architectural space can be obtained by means of the enhancement of the sensory perceptions. Multi-sensory intelligent architecture can not only improve the level of the indoor environment but also contribute to some other things. For example, the indoor space of the multi-sensory intelligent architecture can bring an interactive sensory experience for people’s learning, reading, working, resting and playing [88] to improve people’s impairments in movement skills and social abilities, such as motor delays, social interaction and nonverbal communication difficulties [24]. It can be expected that there will be more and newer functions that can be obtained from multi-sensory intelligent architecture.

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