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*Systematic Review*

# Conceptual Framework to Support Personalized Indoor Space Design Decision-Making: A Systematic Literature Review

**Kyung-Tae Lee , Jin-Bin Im , Sang-Jun Park and Ju-Hyung Kim ***

Department of Architectural Engineering, University of Hanyang, Seoul 04763, Korea;
ktlee0422@hanyang.ac.kr (K.-T.L.); jbim0202@hanyang.ac.kr (J.-B.I.); sangjpark@hanyang.ac.kr (S.-J.P.)
* Correspondence: kcr97jhk@hanyang.ac.kr; Tel.: +82-02-2220-0304

**Abstract:** COVID-19 has forced people to spend more time indoors due to lockdown and social distancing, and clients demand personalized indoor spaces designed to increase individual satisfaction indoors. Consequently, various fourth industrial revolution technologies have been applied to support construction spaces to satisfy those clients lacking architectural knowledge and experience by reflecting individual tendencies and perceptions to build personalized indoor spaces. Therefore, it is crucial to understand how users evaluate the space according to behaviors and emotions felt in the space. A systematic review is performed to integrate significant categories from multiple disciplines to investigate the various decision-making aspects. In this study, 124 papers were selected, applying the PRISMA checklist to conduct a systematic literature review with scientometric analysis to propose a conceptual framework by reflecting the research trend related to indoor space decision-making. Accordingly, research on indoor space decision-making is increasing with pursuing convergence with various fields of study. The research is focused on the following four clusters: indoor space components, human tendencies, technology, and spatial evaluation. The framework proposed by integrating these trends could be utilized by clients as a practical tool to support people-centered indoor space decision-making post-COVID-19. Moreover, a framework should be developed to expand effectiveness in indoor spaces through convergence and collaboration research with psychology, physiology, and the medical field.

**Keywords:** indoor space design decision-making; systematic literature review; personalized space; indoor space components; human tendency; technology; spatial evaluation; COVID-19



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## 1. Introduction

Indoor space is critical in improving people's quality of life. As the concept of indoor space changes according to visual, physical, and functional interrelationships between users and spaces, space cannot be considered separately from humans [1]. Since indoor spaces directly affect the users' behaviors, moods, and activities, designing spaces considering diverse perspectives to operate and create a sustainable space is necessary [2]. People's interest in indoor space continues to develop, and the technology to support decision-making has been advanced as personalization becomes increasingly important [3,4]. Moreover, the COVID-19 pandemic has forced people to spend more time indoors due to the lockdown and social distancing. Thus, interest in interior and indoor environment quality (IEQ) has expanded to increase the satisfaction of clients. As the emphasis on ventilation and air-filtration increased, research was conducted on operating systems such as thermal comfort and air-conditioning, as well as operational guidelines developed in different countries [5,6]. These studies are more concerned with the environmental point of view and focus on establishing systems and preventing virus transmission rather than making personal decisions that reflect human preferences. However, it is necessary to conduct research on interior design that could satisfy indoor activities with psychological satisfaction and classify resident-centered space designs such as wall color, pattern, and ceiling height according to individual preferences to support decision-making [7–9]. Naturally, interest in how to organize indoor spaces for personal preferences is also increasing [10–13]. As a result, indoor space should be analyzed in terms of the classification of human tendencies and behavioral patterns based on different evaluation tools, such as emotional and cognitive approaches. These approaches must be integrated and adopted to arrange indoor components according to each function of the space.

Indoor space design decision-making is a holistic synthesis that defines individual behavior and utilizes information held through various perception processes in space to produce the ideal results [14]. Consequently, it is necessary to address the human perception process and comprehend the emotions and characteristics of humans in the personalized space. Although there is a limit to categorizing people's behavior and tendencies, studies have been conducted to typify people using developed models through psychological and behavioral analysis approaches. Nowadays, they have been caught as a trend [15,16]. Therefore, developing a framework on how people process spatial information is required to supplement the decision-making of indoor space design and understand how people evaluate space [17].

However, when a client does not know what they prefer, communication between construction practitioners and end-users is essential but complex owing to differences in information and knowledge. As a result, cost excess and conflicts often occur between clients and practitioners due to the redesign/reconstruction and dissatisfaction with the constructed space. Moreover, although clients can make decisions by receiving real-time information using various technologies, end-users are often excluded from the design process, or the sense of reality or immersion in the technology is decreased [18]. However, as technology develops radically in the Fourth Industrial Revolution, visualization of indoor space through applying virtual reality or 3D models has become more realistic. It emphasizes the visual part of the design with a high level of immersion so that users can feel the space intuitively, helping clients decide on indoor space components. Thus, a direction for how to utilize and apply the advanced technology for active participation of clients should be suggested for a progressive decision-making process centered on individuals and end-users of indoor spaces.

Since the outbreak of COVID-19, the demand for personalized spaces with client participatory decision-making has been increasing due to the change in the utilization of indoor spaces to carry out work and rest in one space. Accordingly, research has been conducted to propose improved indoor spaces and obtain different types of information regarding clients to create user-centered spaces. In the new-normal era of blurring work and home, it is necessary to study a way to make spaces user-centered through interior design rather than controlling the indoor environments through devices to increase cognitive function and achieve social and psychological well-being. More specifically, research has been conducted applying various factors of spatial composition (lightness, brightness, color, material, etc.) and technologies (virtual reality, artificial intelligence, simulations, etc.). However, general frameworks that combine human tendency, technology, and indoor spaces are rarely proposed. This type of framework could serve as an integrated tool to overcome the information and communication limitations between construction practitioners and end-users [1,19,20]. Therefore, this study aims to conduct a systematic literature review to propose a conceptual framework using online databases for supporting personalized indoor space composition decision-making. To this end, a literature review was conducted to answer the main research questions:

- What components should be considered for indoor space design decision-making?
- How do people evaluate indoor space and make decisions about the indoor space design?
- In what direction should research be conducted to support clients lacking architectural knowledge make indoor space decisions that they are satisfied with?

Thus, a total of 124 research articles published in the 21st century were extracted from the Scopus and Web of Science databases through a systematic process, and scientometric analysis was conducted. Through this process, past research trends were identified along with factors that should be considered for people-centered spaces. By suggesting a conceptual framework that integrates these perspectives, convergence research was proposed for practical application.

The remainder of the systematic review process is organized as follows: Section 2 presents the review materials and procedures of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) used in this study. Section 3 reports the findings of quantitative and network analyses. Section 4 provides a detailed discussion and proposes a conceptual framework based on the results of the analysis. Moreover, the authors outline the limitations of past studies and propose directions for future research. Lastly, Section 5 presents the conclusions of the study.

## 2. Materials and Methods

### *2.1. Study Design*

This study was conducted according to a systematic literature review procedure. A systematic literature review was adopted as the research design compared to traditional reviews, allowing the authors to understand the body of knowledge in selecting papers and proposing a research model through a robust, reproducible method while linking the model with the direction of future research [11,21,22]. This process makes it possible to comprehend the research trends and determine the extent to which each country and research field currently follows these trends [23].

### *2.2. Search Strategy*

A systematic literature review was guided by methodological steps based on PRISMA and proceeded based on the proposed checklist [11,24]. It comprises four processes: (1) selection of search engines and keywords, (2) selection of studies based on the keywords, (3) quantitative literature analysis, and (4) results analysis and discussion [21,23].

### *2.3. Data Sources and Data Extraction*

The detailed process of identifying the data used in this study based on the search strategy is as follows:

Step 1: The multi-disciplinary citation search engines, Web of Science and Scopus, were used to find the relevant papers that have undergone blind review academically. These engines directly input the advanced code to help research proceed by systematically extracting the papers while maintaining the consistency of the contents. In addition, the keywords were selected with a focus on “interior design”.

Step 2: The search used advanced database search strategies on keywords combined with Boolean operators such as AND, OR, and NOT to find related papers. Table 1 shows the advanced search code to extract papers in this study. The main term conducted in this search was “interior design”. As the goal of this study is to understand the research trends and future research direction related to interior design factors and personalized indoor space design decision-making, the authors focused on understanding the factors of interior design such as walls, corridors, and layouts, including ventilation and lightness.

**Table 1.** Advanced search code electronic database for study with limitation.

| Name of Electronic Database | Advanced Search Code |
|---|---|
| Web of Science | TS = (interior AND space AND building) AND AK = (design) NOT AK = (Energy) |
| Scopus | ALL (“space” AND “building” AND “interior”) AND KEY (“design”) AND KEY (“interior”) AND NOT (“energy”) |

Step 3: As a result of quantitative literature analysis, 835 papers (Web of science: 155 + Scopus: 680) were found, and the papers were extracted through the following five steps, illustrated in Figure 1.

① Papers based on the keywords in Table 1: 935 (Web of Science: 256, Scopus: 679);
② Included journals and conference papers published between 2000 and 2021: 631 (Web of Science: 146, Scopus: 485);
③ Included papers written in English: 712 (Web of Science: 134, Scopus: 468);
④ Subtracting 13 overlapping papers and self-citations were not performed to increase the objectivity of this study. The number of papers related to indoor space design decision-making was selected for reading the titles and abstracts: 203 (Web of science: 58, Scopus: 145);
⑤ Analyzed papers while conducting qualitative assessment and literature review of full papers: 124 (Web of science: 42, Scopus: 82).

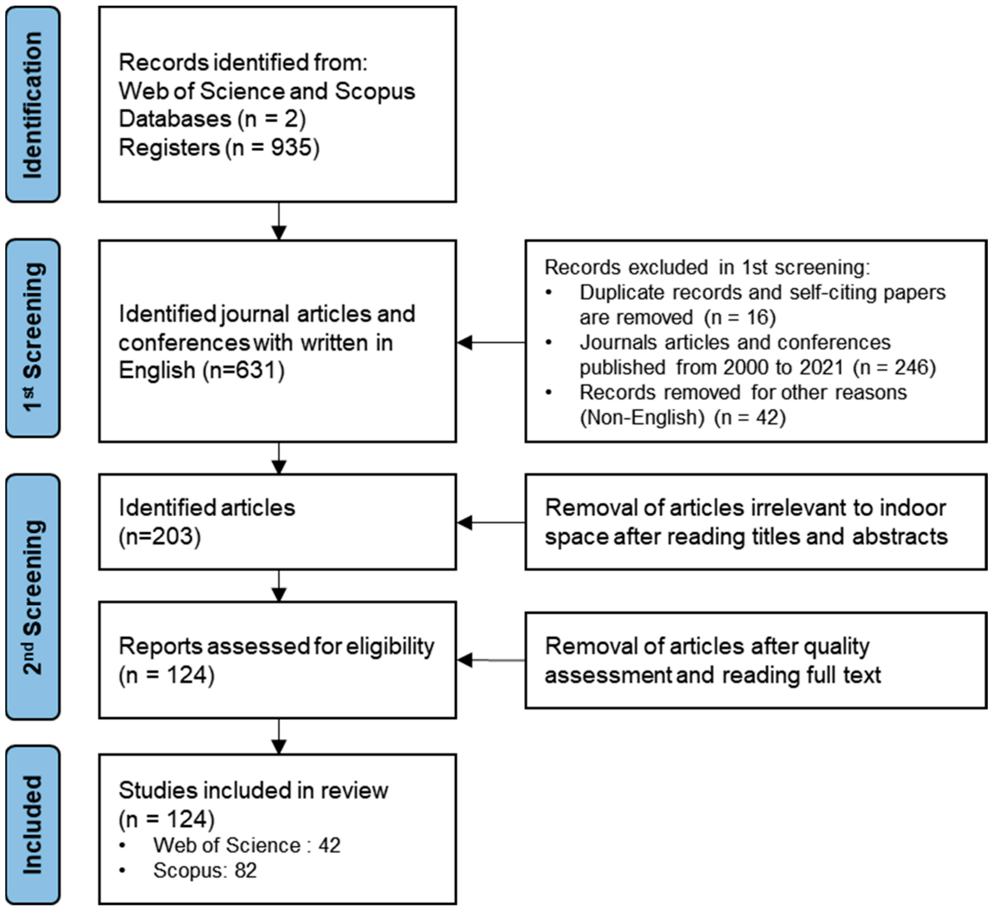


**Figure 1.** PRISMA flowchart for identifying papers.

Step 4: Result analysis and discussion

The results were based on a scientometric analysis, which enables a broader approach. Compared to bibliometric analysis, which focuses on the papers, scientometric analysis helps to understand research trends and comprehensive approaches through bibliometric tools, methods, and data [22,25]. The scientometric analysis of reviewed papers considers the contribution by year of publication, source, and country. A network of the co-occurrence of keywords and abstracts was produced by feeding the bibliographical data (CSV file) to VOSviewer, a free text-mining software, available at www.vosviewer.com (accessed on 4 January 2022); the software provides visualized figures based on a network of words. As a result, the clusters formed by analyzing the co-occurrence of words were identified, and analysis was conducted focusing on keywords representing each cluster.

## 3. Results of Scientometric Analysis

This section presents the results of the scientometric analysis based on 114 papers classified by the designed method. The analysis indicates the statistical and quantitative analysis of each paper to help identify the overall research trend. Subsequently, network analysis was conducted using co-occurrence words in the keywords and abstracts. Through the visualization of the knowledge domain, it is possible to determine whether studies are intellectually connected and organized [11,26].

### 3.1. Quantitative Analysis

As depicted in Figure 2, the document distribution throughout the years exhibits growth in the number of papers. As a result of obtaining the linear regression equation using the number of published papers by year, it shows a positive gradient that the number of papers related to indoor space and interest in personalized space research is continuously increasing annually. In particular, the number of papers has been steadily increasing since 2010. After the COVID-19 outbreak, there has been a remarkable increase in the interest in indoor spaces, and research has been increasing as personalized design decisions on space are required. Previous studies have focused on how to construct and arrange spaces. However, in recent years, studies have been conducted to enhance the understanding of the relationship between indoor space and humans. It is often customized by considering the relationship through various analyses, such as human emotions and personality.

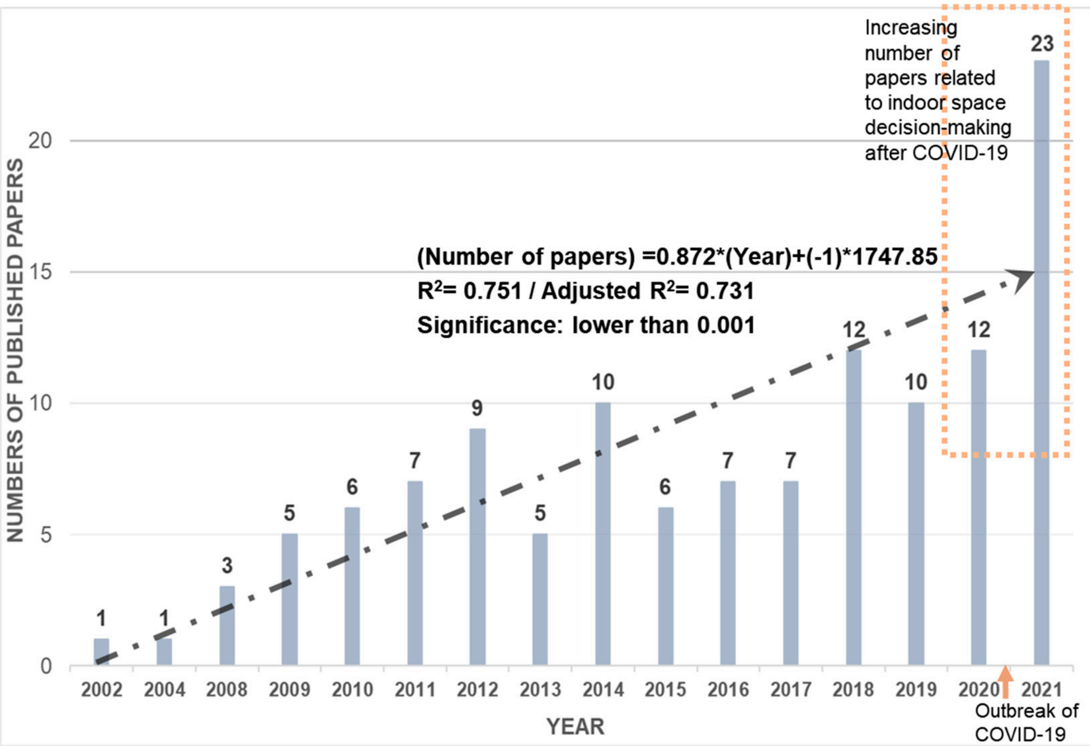


**Figure 2.** Number of papers published by year with regression equation.

Furthermore, the authors analyzed the number of published journals, citations, and papers included in the journal. Of the 124 papers included in this study, these were published in 58 journals. Figure 3 illustrates journals publishing two or more papers, and the percentage among the 114 extracted papers is represented by blue histograms. Moreover, the citation numbers of papers included in the journal are represented by a black line graph. Applied Mechanics and Materials, Advanced Materials Research, Building and Environment, Sustainability, Buildings, and Frontiers of Architectural Research have the highest number of papers published in a journal. Although various papers have been published in journals mainly related to indoor space and construction materials, it was found that papers on technologies such as computer graphics or convergence studies related to psychology or the environment are also being written. Additionally, ACM Transactions on Graphics, Building and Environment, Frontiers of Architectural Research, Lighting Research and Technology, and Sustainability have the highest number of citations in order. Although only two papers were published in ACM Transactions on Graphics, they were highly influential and have been widely cited. These papers improved the interaction between interior design and various technologies by introducing virtual reality and layout optimization based on Artificial Intelligence to propose guidelines for improved indoor space design.

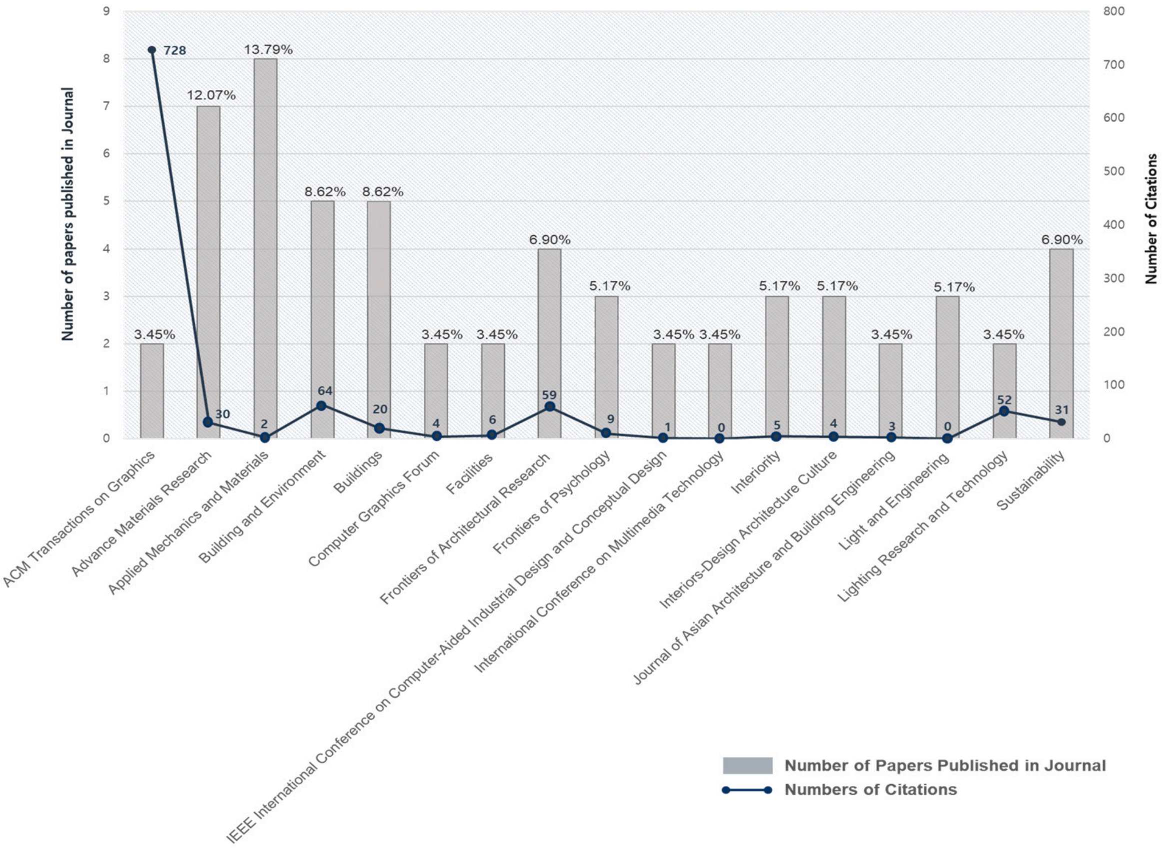


**Figure 3.** Number of papers published and citation of each journal.

Lastly, the countries that published the journal of the papers included in this study are shown in Figure 4. The United Kingdom has the highest number of publications (13), followed by the United States (12), Switzerland (5), and Netherlands (5). Moreover, Germany (4), China, Japan, and Turkey (2) published documents related to indoor environment decision-making and architectural design.

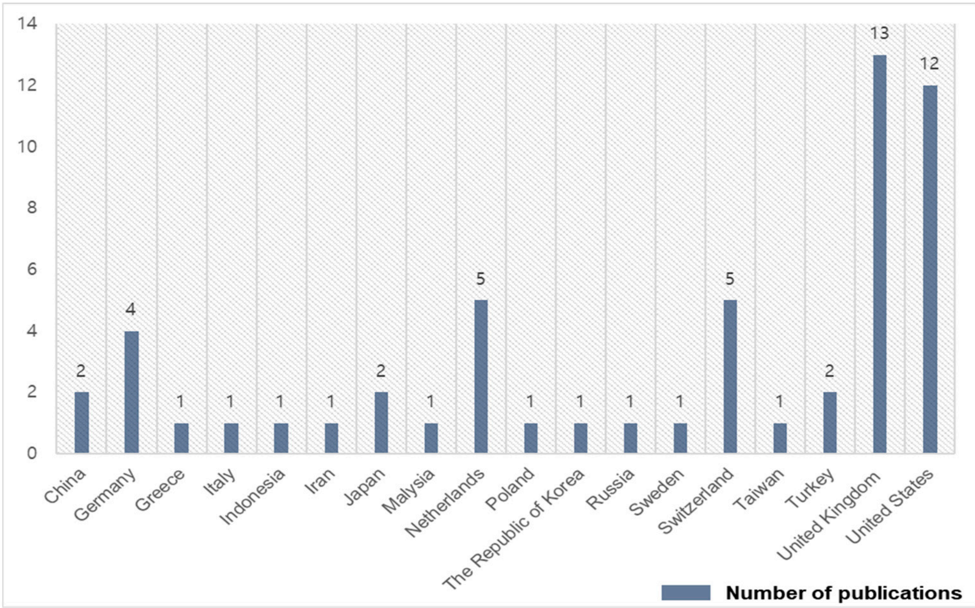


**Figure 4.** The number of papers published by country.

### 3.2. Network Analysis and Overall Content Analysis

The keywords and abstracts of 114 papers included in this study were extracted into a CSV file for network analysis. The CSV file was transferred as bibliographical data to the VOSviewer software. The bibliographical data were utilized to create a network of words using co-occurrence links. The results of the network analysis are depicted in Figure 5. The diameter of the network keyword described through VOSviewer is related to the frequencies with which the word appears, and the distance between the keywords demonstrates the relationship between them [22,26]. More specifically, the larger the diameter, the higher the frequency, and the closer the keyword is, the deeper the relationship is.

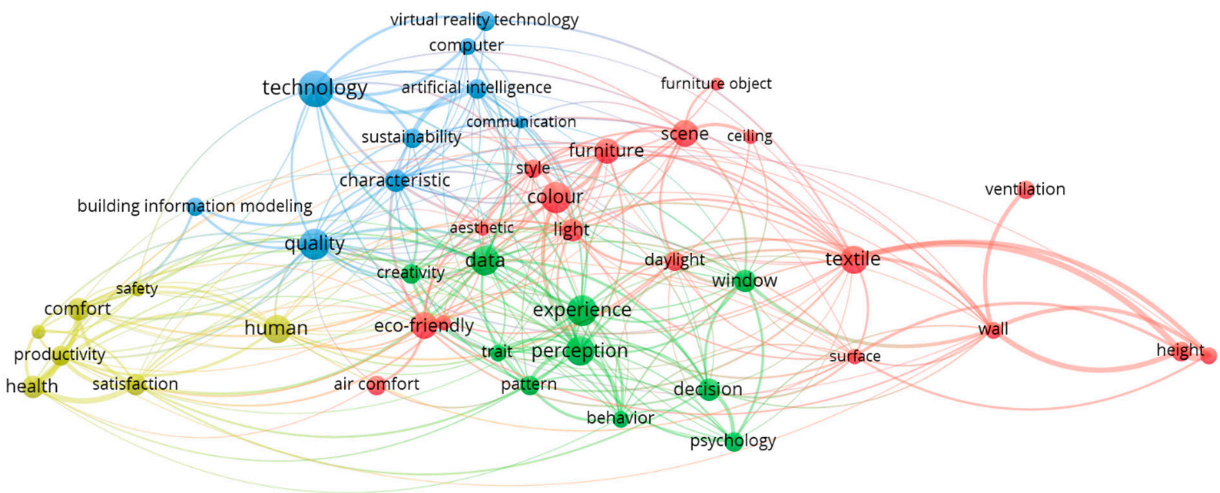


**Figure 5.** Network analysis results of co-occurrence of keywords and abstracts.

Keywords that are deeply related create clusters in the network, and each cluster appears in a different color. Each cluster exhibits the research trend for indoor spaces and illustrates what is critical in this field. Table 2 lists the research trends based on the main keywords and other keywords based on network analysis according to the color of each cluster, as shown in Figure 5. Four clusters were identified, and the characteristics of each cluster were analyzed while fully reading the included papers.

**Table 2.** Cluster results through network analysis for co-occurrence.

| Cluster | Main Keyword | Other Keywords | Example Reference | Main Topic |
|---|---|---|---|---|
| Cluster 1 (red) | Colour | furniture object, light, textile, wall, height, surface, aesthetic, ceiling, ventilation | Celadyn [18], Nasybullina, Samogorov and Shchepetkov [8]; Celadyn and Celadyn [26]; Rasli et al. [27] | Indoor space design components |
| Cluster 2 (green) | Experience | perception, psychology, behavior, decision, creativity, trait, tendency | Karol and Smith [15]; Banaei et al. [28] | Tendency of people and behavior in space |
| Cluster 3 (blue) | Technology | computer, quality, building information modeling, artificial intelligence, virtual reality technology | Darko et al. [26]; Ji, Kang and Jun [29]; Hosseini, Yazdani and Fuente [30] | Fourth industrial technology |
| Cluster 4 (yellow) | Human | comfort, satisfaction, safety, privacy, productivity, health | Candido, Chakraborty and Tjondronegoro [31]; Krukar, Mavros and Hoelscher [9] | Human environmental perception |

#### 3.2.1. Cluster 1: Indoor Space Design Composition

As a result of reviewing the entire text, this cluster was found to deal with indoor space components primarily. Components proceeding with the decision-making of the indoor space include wallpapers, ceiling, corridor, and window. The main attributes are considered the color, material, height, light, layout, and furniture arrangement constituting the space. Owing to the recent trend of “green architecture”, installing plants and the artificial arrangement of water in the indoor space is considered part of the components of indoor space [32–36]. Although there are research results that suggest that building a room to simulate nature improves physical and mental health, it could cause negative problems such as difficulty in humidity control, structural problems, and insect trouble. Therefore, multifaceted consideration is required to support the client’s design decision-making [37]. Furthermore, due to the influence of COVID-19, various types of work, such as remote working and telecommuting, and national policies like the lockdown and social distancing, time spent at home has increased. Since various activities are now handled indoors, several clients need a complex space for rest and work [13,38]. As COVID-19 spread, the concept of biophilia was developed. Biophilia is more than a philosophy that needs to be introduced in the industry; biophilic design is the process of building a nature-friendly space. It is not only to incorporate spaces that are healthier and better for the environment but also to help with emotional affiliation and stress relief [37,39]. To implement this concept, construction practitioners used natural materials (timber, wood panels) with wide corridors, high ceilings, or wide windows to create openness and incorporate the sun to maintain sustainability [40,41]. Moreover, biological walls and colors such as green and various earth tones attempt to connect people with nature and obtain the psychological impacts of nature-like features in built environments [19].

The classification of indoor space design composition based on previous research is shown in Table 3. As shown in Table 3, research on indoor space components was often conducted by changing the color and pattern of wallpaper, primarily because people focused on changes in these factors to visually recognize a space [42,43].

**Table 3.** Summary of the literature review of indoor space components.

| Indoor Space Components | | Goal | Reference | Numbers of Publications per Year | |
|---|---|---|---|---|---|
| **Composition** | **Attribute** | | | | |
| Corridor | Width | Identifying the efficiency of movement in a school or company | Zhang and Park [43]; Oberfeld and Hecht [44]; Aresta and Salingaros [45]; Doucet et al. [46] | 2011<br>2020<br>2021 | 1<br>1<br>2 |
| | Length | Understanding how to efficiently arrange the rooms in schools or companies | Zhang and Park [43]; Zhang and Anderson [47]; Doucet et al. [46] | 2020<br>2021 | 1<br>2 |
| | Height | Identify the stiffness or user comfort felt by users | Zhang and Park [43]; Oberfeld and Hecht [44]; Doucet et al. [46] | 2011<br>2020<br>2021 | 1<br>1<br>1 |
| Wall | Pattern | Determining the pattern and shape of the wallpaper (triangle, diamond, circle, fractal, etc.) and considering user satisfaction. | Lee [20]; Celadyn and Celadyn [27]; Afacan [39]; Aresta and Salingaros [45]; Banaei, Ahmadi, and Yazdanfar [47]; Rounds, Cruz-Garza and Kalantari [48]; Özgen, Afacan, and Sürer [49]; Winton [50]; Wang and Liu [51]; Imamoglu, Senyapili and Demirbas [52]; Javadi et al. [53]; Gerstweiler et al. [54]; Shin and Lee [55] | 2009<br>2012<br>2015<br>2017<br>2018<br>2019<br>2020<br>2021 | 1<br>1<br>1<br>1<br>1<br>2<br>1<br>5 |
| | Color | Through changing the color of the wall, such as red, green, blue, black and white, researchers found out which color clients prefer and which color they choose based on the type of industry and space. | Lee, Shin and Lee [16]; Banaei et al. [29]; Balta and Read [35]; Fontán et al. [41]; Siverson [42]; Oberfeld and Hecht [44]; Aresta and Salingaros [45]; Doucet et al. [46]; Banaei, Ahmadi, and Yazdanfar [47]; Imamoglu, Senyapili and Demirbas [52]; Gerstweiler et al. [54]; Shin and Lee [55]; Odabaşioğlu [56]; Chen et al. [57]; Yuan and Zhang [58]; Weibel et al. [59]; Jin and Juan [60]; Chiamulera et al. [61]; Oberfeld, Hecht, and Gamer [62]; Bai [63]; Qiang [64]; Rui and Correia [65]; De Wei, Zhang and Zhu [66]; Ergan, Shi and Yu [67]; Kwon and Kim [68]; Motalebi and Parvaneh [69]; McKellar [70] | 2008<br>2009<br>2010<br>2011<br>2014<br>2015<br>2016<br>2017<br>2018<br>2019<br>2020<br>2021 | 1<br>1<br>2<br>2<br>2<br>2<br>1<br>2<br>4<br>3<br>3<br>4 |
| Ceiling | Height | Identify the efficiency of human emotions and work concentration | Krukar, Mavros, and Hoelscher [9]; Celadyn [18]; Fontán et al. [41]; Oberfeld and Hecht [44]; Aresta and Salingaros [45]; Gerstweiler et al. [54]; Oberfeld, Hecht, and Gamer [62]; Erkan [71] | 2010<br>2011<br>2018<br>2019<br>2020<br>2021 | 1<br>1<br>2<br>2<br>1<br>1 |
| Material | Type | Based on materials, such as wood, concrete, and marble, the analyses identify the preferred materials depending on the type of work and the use of the place. | Krukar, Mavros, and Hoelscher [9]; Celadyn [18]; Celadyn and Celadyn [27]; Aresta and Salingaros [45]; Shin and Lee [55]; Oberfeld, Hecht, and Gamer [62]; Rui and Correia [65]; Yi [72]; Wang and Hu [73]; Fakere, Arayela and Folorunso [74]; Xue [75]; Li, Hu and Wang [76]; Kán and Kaufmann [77]; Canepa and Vaudetti [78] | 2010<br>2011<br>2012<br>2013<br>2017<br>2018<br>2019<br>2020<br>2021 | 1<br>3<br>1<br>1<br>2<br>1<br>2<br>1<br>2 |
| Furniture | Arrange-ment | Identification of preferences according to the arrangement of chairs, tables, beds, etc., and investigate the work efficiency and rest by | McKellar [70]; Kán and Kaufmann [77]; Alqahtani [79]; Yu et al. [80]; Vecchiato et al. [81]; Artayasa [82]; Wang, Cui and Xu [83]; Cys and Lawrence [84]; Barbosa et al. [85]; Kim and Heo [86]; Nash, Geck and Miller [87] | 2011<br>2012<br>2013<br>2015<br>2016<br>2017<br>2021 | 1<br>2<br>1<br>3<br>1<br>1<br>2 |

**Table 3.** *Cont.*

| Indoor Space Components | | Goal | Reference | Numbers of Publications per Year | |
|---|---|---|---|---|---|
| Composition | Attribute | | | | |
| | | conducting regular and irregular arrangements of furniture. | | | |
| Window | Openness, Lightness | Change the degree of window disruption by ratio, identify the type and efficiency of the work should be completed based on the contrast of the room including both natural and artificial lightning. | Nasybullina, Samogorov and Shchepetkov [8]; Jin and Lee [19]; Zhong, Schröder and Bekkering [37]; Afacan [39]; Odabaşioğlu [56]; Cuttle [88]; Jamaludin et al. [89]; Nasar and Bokharaei [90]; Siverson [42]; Ergan, Shi and Yu [67]; Motalebi and Parvaneh [69]; Cuttle [91]; Tahbaz and Sanati [92]; Newsham et al. [93]; Bin Zainudin and Bin Md. Isa [94]; Kasapseçkin and Altuncu [95]; Li and Samuelson [96]; Indraprastha and Shinozaki [97]; Voronov and Shchepetkov [98] | 2004<br>2008<br>2010<br>2011<br>2012<br>2013<br>2015<br>2017<br>2018<br>2019<br>2020<br>2021 | 1<br>2<br>1<br>1<br>1<br>1<br>2<br>1<br>2<br>1<br>2<br>4 |
| Ventilation | - | Creating an energy-Efficient building and providing thermal comfort through an effective natural ventilation system. It also enables sustainable air exchange, increasing the quality of life of the occupants. | Kim et al. [4]; Guo et al. [6]; Lee [20]; Rasli et al. [27]; Qu [35]; Megahed and Ghoneim [99] | 2020<br>2021 | 2<br>4 |
| Layout | - | Discussion of the arrangement of each room in school and workspace was conducted by considering the efficiency of movement in space. | Oberfeld and Hecht [44]; Merrell et al. [100]; Zhang and Wang [101]; Wu et al. [102]; Nicholas, Smith and Francisco [103]; Liu et al. [104] | 2010<br>2011<br>2013<br>2018<br>2021 | 1<br>2<br>1<br>1<br>1 |
| Plant | - | Identified the effect of plant placement in space on the user's satisfaction and health recovery. | Shi and Wang [32]; Dash [33]; Celadyn [34]; Qu [35]; Zhong, Schröder and Bekkering [37]; Vallet and Tyl [105]; Chen and Shi [106] | 2014<br>2018<br>2020<br>2021 | 2<br>1<br>3<br>1 |
| Stair | - | Identified the convenience and movement of stairs before and after installation. | Lee, Shin and Lee [16] | 2020 | 1 |

The decision-making of the corridor was about width and length which can give various layout of indoor space [44,47]. The wallpapers used for research were often red, green, blue, black, and white, and as a result, depending on the color being shown, human psychological and physiological changes occurred [44,46,98]. Although it varies by gender and age, there is a high preference for bright colors such as white, green, and blue [63,65,105–109]. After quantitatively surveying emotions or preferences, statistical analysis was performed, and action research was conducted to observe their behaviors in indoor spaces created to reflect their preferences. It was concluded that teenagers prefer a blue color that they can think of as the sky or achromatic colors such as white [107]. However, older adults prefer green colors because they are the most like nature [39,108]. Although white or green space makes indoor environments clear and spacious, warm colors are preferred because they evoke positive emotions and create a feeling of coziness and calm. Additionally, several scholars have studied the pattern and shape of walls and the material of the floors and walls in indoor spaces [20]. Materials used in the studies included wood, marble, and concrete, and metaphorical and morphological designs on the walls by displaying various patterns (triangle, diamond) or natural forms (fractal) to improve the senses of the users [37,46,109,110].

The participants' cultural influences or personal experiences affect their choice. A psychological survey regarding the level of comfort and pleasantness or the degree of concentration and task load through a simple cognitive test was used to verify the individual's choice [54]. Most previous research focused on aesthetics and the unique atmosphere felt by applying materials in the interior [72,73]. However, in current research trends, the biological, environmental, and sustainability factors of developed materials have increased [23,39,50,74,95]. Therefore, the interaction between humans and nature was increased by reducing gas emissions and labor resources and using sustainable materials to create a natural space with a lower carbon footprint [39]. Moreover, studies on the arrangement and layout of furniture have been conducted. However, ergonomics, such as table and chair height, indicated that differences in the arrangement of a layout and preferred furniture exist according to the user's behavior patterns [74,79,80,100]. Additionally, several studies on lightness and openness have been conducted. Indoor spaces have various feelings depending on the brightness [62,78,88,101]. Therefore, the arrangement of windows can adjust the amount of light coming in. The difference in space impression caused by illumination can affect user satisfaction and space utilization [88–90]. The installation of windows is also related to ventilation. Rasli et al. [27] stated that when a wood panel window is made at an angle of 75°, it not only prevents rain and smoke but also improves thermal comfort and indoor air quality. Moreover, air purification and indoor humidity through adaptive façades can increase the building occupant's quality of life as well as the aesthetics [20]. Ventilation is being studied further regarding the prevention of virus transmission through indoor spaces. In addition, mechanical filtration and bio-filter technology were studied to support the maintenance and monitoring of indoor spaces [75]. The design and construction of ventilation systems provide a positive impact on indoor temperature and humidity and prohibit respiratory diseases. Therefore, the correct use of ventilation systems helps to increase the task load by activating psychophysiological responses [4,6].

#### 3.2.2. Cluster 2: Tendency of People and Behavior in Space

In the second cluster, several studies were conducted on human spatial perceptions and experiences in space. The propensity of humans and their behavior in space were analyzed, and human experience, psychological traits, such as temperament, and personality were identified through interviews and questionnaires. Table 4 illustrates the classification of the studies conducted by the researchers.

**Table 4.** Summary of the literature review on human tendencies and behavior in indoor space.

| Factors Influencing Spatial Perception of Human | Goals | Reference | Numbers of Publications per Year | |
|---|---|---|---|---|
| Temperament, trait | Categorization of people and their tendencies are identified through the results of various psychological tests (Big Five, Myers Briggs Type Indicator (MBTI), Temperament and Character Inventory (TCI)) | Karol and Smith [15]; Banaei et al. [28]; Dash [33]; Sedighi and Mollazehi [36]; McKellar [70]; Alqahtani [79]; Wang, Cui and Xu [83]; Dong, Wen and Chen [111] | 2012<br>2015<br>2017<br>2018<br>2019<br>2020 | 2<br>2<br>1<br>1<br>1<br>1 |

**Table 4.** *Cont.*

| Factors Influencing Spatial Perception of Human | Goals | Reference | Numbers of Publications per Year | |
|---|---|---|---|---|
| Behavior | Individual emotion and degree of interest are evaluated through behaviors, such as walking and eye gazing. | Krukar, Mavros and Hoelscher [9]; Lee, Shin and Lee [16]; Yuan and Zhang [58]; Weibel et al. [59]; Ergan, Shi and Yu [67]; Kwon and Kim [68]; Erkan [71]; Kaasalainen and Huuhka [112]; Zhang, Li and Liu [113] | 2016<br>2018<br>2019<br>2020<br>2021 | 1<br>3<br>2<br>2<br>1 |

Human space perception is identified through analyzing behaviors, such as eye-tracking and walking, in space [33,43,53,67,69,70,114]. With the increase in people-oriented concepts, research has been conducted on psychological traits that arise according to age groups by proposing spaces for young students and elderly people [58,83,111,112]. Moreover, as interest in health increases, design studies have been conducted to improve individual self-esteem, identity, physical improvement, and satisfaction of sick people in indoor spaces, such as attention-deficit/hyperactivity disorder (ADHD) and cognitive impairment [16,69,110]. Temperament and tendencies were identified using psychological tools and scales developed by existing psychologists and researchers to comprehend individual tendencies through a psychological approach. For example, the Big Five test was conducted, and for this purpose, the Neuroticism-Extraversion-Openness Five Factor Inventory (NEO-FFI) test, adapted and used in Germany, was employed to identify human temperament [28]. The influence and preference of the indoor space were presented by statistical analysis (ANOVA, multiple regression analysis) after tendency of the experimenter and the emotions felt in the experimental space were identified by several tests. Consequently, customized design according to a person's trait becomes possible. People with neuroticism dislike curved shapes, but those with openness to experience have a negative mindset about straight-pointed spaces [28,36].

Furthermore, certain visual stimuli or a change in an indoor environment could influence an individual's psychological behavior. For example, hot and humid environments could cause an individual to open a window to increase ventilation. Studies relating to an individual's behavior reflecting a modification in the environment were conducted regarding the stride size of the experimenters and comparing their primary walking and its pattern in different environments [16,58,70]. Moreover, researchers used a virtual environment to determine what kind of indoor space factors the experimenters were interested in and made decisions according to the subjects' gaze through eye-tracking [68–70,112,113]. It was then described as how to compose the space or identify individuals' interests. Alternatively, research on indoor space design has been conducted based on emotions, joy, stress, and resilience from the experience that individuals feel in the space [66]. In addition, each person's culture and age influence their behavior in a space. According to oriental Fengshui consideration, the body's ability and other social behaviors change due to psychophysiological states [60]. As the behavior changes due to experiences and habits with age, the indoor space requires changes [16,103,115]. Consequently, when the tendency of the person and the individual's behavior performed in the space is identified, personalized indoor spaces could be constructed by reflecting these as much as possible.

#### 3.2.3. Cluster 3: Technology

The third cluster demonstrates various technologies developed to visualize indoor spaces to support decision-making. As the fourth Industrial Revolution progresses, various technologies are being developed to solve asymmetry resulting from information opacity and the knowledge gap between practitioners and clients to support personalized indoor design decision-making. The priority of developing a model for a personalized space involves classifying the characteristics and components of the space. As technology improves, a model including high-quality information could be provided to support decision-making.

Table 5 lists the technologies that were applied in the experiments. Building information modeling (BIM) is a representative technology based on three-dimensional (3D) modeling, through which decisions are made, and the information about space and resources used for construction is obtained [10,55,94,116]. Additionally, virtual reality (VR) is utilized to increase the sense of immersion beyond visualization of the space and provide the feeling of experiencing personalized space directly [2,60,63,87,117–120]. To overcome the unreality of the VR environment, it is expanding to mixed reality (MR), combining the real world with the digital world. Thus, VR and MR technologies are assistive tools that will be implemented for various personalized space design decision-making more conveniently and intuitively [49,61,92,121]. Accordingly, the indoor space is personalized in various ways, such as accepting the emotions felt in the space and utilizing the space and furniture arrangement. Moreover, when the 3D model does not exist for remodeling projects built a long time ago, the space is laser-scanned, and the existing space is reverse-designed based on photogrammetry technology, which calibrates the 3D point clouds [49,96,122,123]. Finally, the optimization process of indoor space composition deployment, such as the arrangement of space and furniture, was conducted using artificial intelligence (AI) technology [102]. For example, Bayesian networks and support vector machines are used to classify and cluster indoor space styles according to types of people to support personalized decision-making [29,44,77,124,125]. In addition, the goal of technology is to support realistic decision-making by conducting simulation and realization of space for laser scanning for building spaces close to reality [126].

**Table 5.** Summary of technologies to support personalized space design decision-making.

| Type of Technology | Goals | Reference | Numbers of Publications per Year | |
|---|---|---|---|---|
| Virtual reality | Proposal of spatial decision making using virtual reality to experience space indirectly to feel reality and immersion | Li et al. [3]; Hinkel [13]; Dosen and Ostwald [17]; Ji, Kang and Jun [29]; Gerstweiler et al. [54]; Qiang [64]; Rui and Correia [65]; Nash, Geck and Miller [87]; Zhang, Li and Liu [113]; Zhou [115]; Jiang [117]; Li [118]; Hsu, Peng and Wu [119]; Lin and Pan [120]; Viet et al. [127]; Rácz and Zilizi [128]; Yan et al. [129] | 2009<br>2011<br>2014<br>2017<br>2018<br>2019<br>2020<br>2021 | 2<br>1<br>1<br>2<br>4<br>3<br>3<br>1 |
| 3D model, computer-based design | Support decision-making by visualizing buildings filled with information in advance through Building information modeling (BIM) and 3D Cad. | Karan, Asgari and Rashidi [1]; Wang [10]; Jin and S. H. Lee [19]; Shin and Lee [55]; Özgen, Afacan, and Sürer [49]; Bin Zainudin and Bin Md. Isa [94]; Liu et al. [104]; Ji and Jun [114]; Rao [116]; Jiang [117]; Li [118]; Virtanen, Kurkela and Hyyppä [122]; Rácz and Zilizi [128] | 2011<br>2013<br>2014<br>2017<br>2018<br>2019<br>2021 | 1<br>2<br>2<br>1<br>2<br>3<br>2 |
| Laser scanning, photogrammetry | Applying the 3d scanner to obtain a 3D environment, obtaining shape information, or progressing reverse design to obtain building information | Virtanen, Kurkela and Hyyppä [122]; Holliss [123] | 2012<br>2014 | 1<br>1 |

**Table 5.** *Cont.*

| Type of Technology | Goals | Reference | Numbers of Publications per Year | |
|---|---|---|---|---|
| Artificial Intelligence, big data; image processing | Space is classified and clustered to categorize the type of space preferred by humans using various algorithms (Support vector machine, k-nearest neighbors (KNN), Bayesian networks, etc.). | Karan, Asgari and Rashidi [1]; Al Khafaji and Kamaran [2]; Wang [10]; Ji, Kang and Jun [29]; Hosseini, Yazdani and Fuente [30]; Chen et al. [57]; Rui and Correia [65]; Kán and Kaufmann [77]; Barbosa et al. [85]; Shen [124]; Bapna and Srinivasaraghavan [125]; Kim and Lee [130] | 2011<br>2016<br>2017<br>2018<br>2019<br>2020<br>2021 | 1<br>3<br>1<br>1<br>1<br>3<br>2 |
| Simulation | Through 3D simulation, the type of the space is presented for various arrangements, and the interior design preferred by people is suggested to grasp the emotions in it. | Liu [126]; Yan et al. [129] | 2014<br>2018 | 1<br>1 |

#### 3.2.4. Cluster 4: Human Environmental Perception

The last cluster describes how people evaluate space. Because the key is to organize the space centered on the people who use the space, making their lives comfortable indoors is the most crucial part of personalized space. In other words, it is imperative to improve the subjective emotions that people feel in space and work more efficiently and healthily than in the existing space. In previous studies, the various reliable indices used for evaluation focused on human emotions, productivity, or others in the space as shown in Table 6.

**Table 6.** Results of literature review on spatial evaluation.

| Category of Environmental Perception | Goals | Reference | Numbers of Publications per Year | |
|---|---|---|---|---|
| Emotion | The emotions that individuals feel in space are quantified through Pleasure, Arousal, Dominance (PAD) tests, Profile of Mood States (POMS) or the State Trait Anxiety Inventory (STAI) tests and presented as a result. | Karan, Asgari and Rashidi [1]; Candido et al. [12]; Karol and Smith [15]; Dosen and Ostwald [17]; Celadyn [18]; Banaei et al. [28]; Candido, Chakraborty and Tjondronegoro [31]; Zhong, Schröder and Bekkering [37]; Afacan [39]; Martinez-Soto, Suarez and Ruiz-Correa [40]; Aresta and Salingaros [45]; Fakere, Arayela and Folorunso [74]; Montanana, Llinares and Page [131]; Xue [75]; Vecchiato et al. [81]; Artayasa [82]; Balta and Read [107]; Petermans and Nuyts [132]; Yasui and Ogino [133] | 2011<br>2012<br>2014<br>2015<br>2016<br>2017<br>2018<br>2019<br>2020<br>2021 | 1<br>1<br>1<br>2<br>1<br>2<br>1<br>3<br>1<br>3 |
| Productivity; Task efficiency | Identified the difference in efficiency after conducting a cognitive test or simple task in space composed by an individual's design decision-making. | Li et al. [3]; Kim et al. [4]; Zhong, Schröder and Bekkering [37]; Afacan [39]; Voronov and Shchepetkov [98]; Yeom et al. [121]; Lee J. [134] | 2010<br>2020<br>2021 | 1<br>4<br>2 |
| Physical health | Improve human-nature relationships and physical fitness of indoor users through the use of sustainable materials and greenery colors and the creation of an environment friendly to nature. | Colenberg, Jylhä, and Arkesteijn [11]; Candido et al. [12]; Cho et al. [23]; Celadyn [34]; Qu [35]; Zhong, Schröder and Bekkering [37]; Afacan [39]; Aresta and Salingaros [45]; Vallet and Tyl [105] | 2020<br>2021 | 3<br>6 |

**Table 6.** *Cont.*

| Category of Environmental Perception | Goals | Reference | Numbers of Publications per Year | |
|---|---|---|---|---|
| Physiological | The EEG, ECG, and heart rate of the human body in space are obtained by identifying individual concentration and tension rate. | Li et al. [3]; Kim et al. [4]; Candido et al. [12]; Ji, Kang and Jun [29]; Doucet et al. [41]; Rounds, Cruz-Garza and Kalantari [48]; Javadi et al. [53]; Weibel et al. [59]; Jin and Juan [60]; Chiamulera et al. [61]; Ergan, Shi and Yu [67]; Erkan [71]; Vecchiato et al. [81]; Indraprastha and Shinozaki [97] | 2012<br>2015<br>2017<br>2018<br>2019<br>2020<br>2021 | 1<br>1<br>1<br>3<br>1<br>5<br>2 |

In indoor spaces, people feel various emotions, such as comfort, safety, and satisfaction. Emotional language tests have been developed and applied by several researchers to study human emotions. Correspondingly, the research was conducted using scales such as the Profile of Mood States (POMS) [39,59], Pleasure, Arousal, and Dominance (PAD) [28,81], which are used widely to quantitatively analyze the emotions and conditions people feel in space [132]. Moreover, categories such as satisfaction, comfort, functionality, and the privacy of users were also analyzed. By objectively evaluating emotions in a space, improving the personalized indoor space environment would improve mental health to proceed with post-occupancy evaluation [108].

Interest in personal physical health indoors is increasing even more after COVID-19, and a number of papers have been published since 2020. In addition, as the concept of biophilia expands, awareness in making interiors similar to nature is increasing. For example, plants are installed to create a green environment to help patients' restoration and various senses, and they help to decrease indoor pollutants such as smoke, dust, and chemicals from paints to reduce the occurrence of skin allergies or respiratory diseases [23,34,37].

As a result of several in-vivo experiments and human experimentation conducted after Institutional Review Board (IRB) certification, living in an environment like nature helps positive ageing and increases psychological satisfaction [12,39,105]. International standards, such as Leadership in Energy and Environmental Design (LEED) and the Green Standard for Energy and Environmental Design (G-SEED), are being proposed for clients to support decision-making based on design strategies and guidelines. However, it is difficult to continuously update it due to the issue of cost, the limitation of alternative materials, and the lack of clarity of the relationship between indoor space and physical fitness [23].

Various studies suggested that the introduction of natural materials such as wood and stone, white and green lighting, and high ceilings make indoor spaces clear and wide and provide positive experiences and moods [19,47,61]. It is important to increase the transmission of sunlight through the window and to use natural colors such as earth-tone and green. Moreover, to introduce the biophilia concept, making appropriate relative humidity through biological devices or wall patterns for indoor air purification is necessary to create a comfortable environment for physical fitness [18,92]. Oriental thinking, like Fengshui (avoiding windows near the head of the bed and rooms shaped square, etc.), also could provide a positive psychological effect [60]. In contrast, excessively bright or high-contrast colors create pressure effects and negative emotions, and glare and spilling light from poorly installed windows interfere with visual performance and create distraction [37]. The oppressive environment caused by the complex layouts and excessive furniture arrangements leads to emotional starvation [45]. Similarly, architectural features such as low window-to-wall ratio, sharp edge, and provocative color, where an individual may have multiple negative experiences, should also be avoided [66]. Not only psychologically but also in terms of physical health, the indoor space where nature cannot be seen or the lack of white or green has adverse effects. In addition, artificial materials such as concrete, polish, and coating paint could yield physical diseases like allergic diseases or neurological effects due to the release of radon and VOCs (Formaldehyde) [11,23].

Simple tasks were conducted to assess work efficiency, and cognitive tests such as the Stroop test, fast-counting test, and calculation experiments [3,4,121]. Space efficiency was directly judged through these tests, and concentration and rest effectiveness were assessed by measuring individual physiological indicators. Physiological indicators can be used to objectively determine space based on human physical measures [134]. Widely used physiological indicators, rest, and vitality in space are objectively determined based on the alpha and beta waves of brainwaves, respectively [3,4,29,48,71,81,98]. Functional magnetic resonance imaging (fMRI) was used to visually observe the shape and area of the brain's activity while using indoor space [46]. In addition, electrocardiograms and heartbeats were measured to evaluate the comfort or fatigue of indoor space users by using smartwatches and blood pressure devices [12,58,59]. Therefore, it is necessary to present a personalized space for increasing satisfaction in it so that individuals can lower stress by decreasing blood pressure and heart rate in the space and improve users' health by enabling physical recovery [40,51].

## 4. Discussion

### *4.1. Proposal of Conceptual Framework for Personalized Indoor Space Design Decision-Making*

This study performed PRISMA using representative online literature databases to classify and include studies related to the indoor environment and space composition and identify different trends related to personalizing space decision-making. The results after reviewing publications in two decades show that the fourth industrial revolution technologies are introduced into the indoor space design decision-making process with a focus on the emotions people feel in space. It also indicates that construction practitioners, such as architects and designers, are responsible for communicating with clients to support the decision-making process for constructing personalized spaces after the outbreak of COVID-19. In particular, the interest in realistic and immersive visualization technologies for supporting decision-making and people's essential traits, emotions, and behaviors is increasing. Ordinary indoor space has developed in a complex way that improves the quality of individual life while performing tasks efficiently according to individual tendencies. Therefore, identifying the association between space and human tendencies is necessary for social well-being with preferred indoor space [11]. In making indoor space decisions in the past, several intellectual approaches to construction and indoor architecture were required to overcome information asymmetry between clients and practitioners. This was because they generally proposed indoor space composition of colors or materials according to interior types, such as modern and natural, or applied new green or ecological spatial composition such as plants and water [32,64,131]. However, after personalization is emphasized and the boundaries between home and workspace are blurred after the outbreak of COVID-19, a convergent understanding of various disciplines, such as neuroscience, psychology, and computer science is required through the development of various technologies and knowledge to support personalized spatial decision-making.

By integrating the results of the quantitative analysis and network analysis based on keywords and paper contents of the data, Figure 6 presents a conceptual framework for supporting clients in constructing a personalized indoor space. As illustrated in Figure 6, technology is increasingly supporting indoor space design decision-making, and representatively, indoor space is visualized in three dimensions, and virtual environments and mixed reality are being employed lied to expand the experience of various indoor spaces. Moreover, the understanding and knowledge of humans are essential for a construction space to be centered on people. As a person's experience, behavior, and tendencies greatly influence their decision-making and preferences for indoor space, categorization of humans will help practitioners to apply practically, and as their personal needs vary depending on their way of life, indoor space should be constructed according to research on people as much as possible [68,72,85,97,111]. Because human tendencies are a subjective factor, as a personal perspective is large, physiological indicators such as EEG and heartrate should also be utilized to present objective standards [48]. Consequently, verification by considering the emotions, work productivity, and satisfaction of the person felt in the space is necessary to evaluate the customized indoor space. Therefore, the conceptual framework proposed by combining these categories can be used to supplement personalized space design decision-making and research directions and is expected to overcome the limitations of knowledge and information between construction practitioners and clients to suggest a people-centered indoor space.

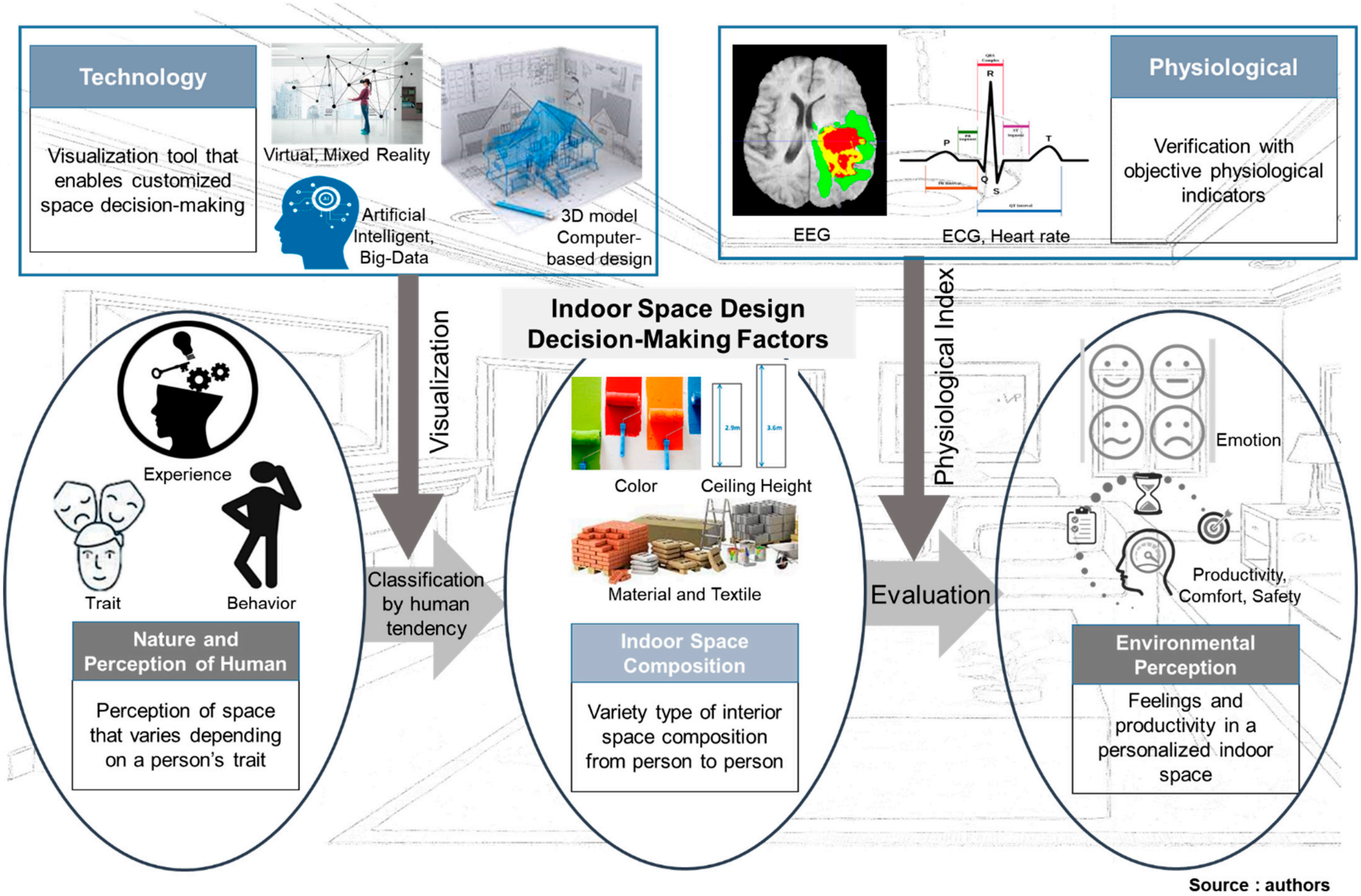


**Figure 6.** Conceptual framework to support personalized indoor space design decision-making.

### 4.2. Limitations and Future Research Directions

Previous studies identified various indoor space constituent factors and conducted human-centered research. However, the limited number of available studies included in this systematic review indicates that quantitative judgement was conducted in most cases. Since quantitative analysis is conducted through surveys or developed scales made by previous research, it is necessary to qualitatively analyze personal experiences through interviews or the Delphi method to reflect individual preferences in more detail. Individual experience is a critical factor that constitutes perception, and this influences the composition in designing a space. Therefore, research needs to be conducted to further emphasize these factors. Moreover, as in previous studies, it is necessary to categorize the space model or type beyond suggesting and defining spatial components according to human tendencies by applying various classification models such as support vector machine and random forest [86,130]. Construction and design practitioners should propose space to clients based on categorized models that will likely develop into user-centered design approaches and inclusive designs beyond academic ones.

The proposed future research direction to overcome the limitations mentioned above is as follows. As mentioned earlier, previous studies primarily focus on the space itself, and there is a limit to making user-centered proposals owing to a lack of multifaceted and convergent approaches. Following the outbreak of COVID-19, in the new normal era, new spaces have reduced contact with people, and there is a growing demand for online meetings and telecommuting rather than physical meetings [13,38]. In other words, homes and indoor spaces can be used in various ways, such as individual workspaces and other areas. In more detail, it is necessary to establish a system and process that proceeds with spatial decision-making in a convergent manner through various research approaches. Moreover, information asymmetry regarding design and construction can lead to conflicts between clients and construction practitioners. Therefore, providing direction for standardizing the decision-making processes through fully utilizing visual tools, such as mixed reality or virtual reality and advanced technologies, is necessary to narrow the gap and increase the efficiency of communication with clients based on realistic and immersive indoor space models [52,119]. People's interest in psycho-physiological health in the indoor environment has also increased. Therefore, it is necessary to find out whether recovery, satisfaction, and positive feelings can be improved in an indoor space by proceeding with research to request the active introduction of methods in the industry, such as creating an environment similar to nature or using similar colors.

Finally, it is necessary to propose an individual space by converging knowledge about the medical field with architecture. As interest in social well-being and health grows, there is a growing demand not only for space to live but also for whether it affects health [23]. As research on furniture arrangement, material efficiency, and light levels is continuously underway to cope with the aging population and people with ADHD and atopic diseases, research trends need to be gradually advanced by combining space and health to develop the proposed conceptual framework to provide medical information for indoor space design decision-making [110]. The framework proposed by integrating the research results can support decision-making by reflecting not only individual subjective preference but also objectivity based on human emotions (pleasure, happiness, sadness) and tendencies (extroverted, emotional). In other words, it is possible to provide satisfactory indoor spaces while shortening the time for clients. In addition, through this framework, it was possible to extend the biophilia concept to make the interior and indoor design similar to nature, reduce harmful chemicals, and lower carbon emissions by presenting a standard that responds to the increased interest in physical fitness after COVID-19. This can practically be sued as a guideline to establish the original international standard in composing a people-centered eco-friendly space.

## 5. Conclusions

This study aimed to highlight factors to support personalized indoor space design decision-making. A comprehensive systematic literature review was conducted with 124 articles about indoor space design. From the review, it was identified that the interests of personalized space should reflect human psycho-physiological conditions through the introduction of various new technologies. Consequently, a conceptual framework for personalized indoor space was proposed by integrating these results.

Psychological and emotions tests are necessary for factors such as: psychological emotions, temperament, and tendency, and the categorization of the influence of the client's preference for space design in the decision making of individuals. Furthermore, various technologies to reduce the information and knowledge gap between construction practitioners and clients were identified; especially in cases of growing remodeling projects that can result in a blurred boundary between work and home.

The novelty of this study comes from network analysis performed based on a systematic literature review. The analysis allows for integrating and presenting a positively elevating indoor space in terms of the emotional and physical health of occupants. Moreover, a conceptual framework that integrates human and technological areas for supporting design decision-making could show the direction for creating a people-centered indoor space.

Consequently, the direction of future research was suggested, including: (1) the convergent approach of humanity, technology, and space is enhanced; (2) the necessity of processes and systems to support indoor space design decision-making for increasing client convenience post COVID-19; and (3) the gradual development of the proposed framework through research on social well-being and physical recovery that concerns changes to space in response to social trends via medical approaches.

In the present era, the interest and significance of space continue to grow. After the breakout of the COVID-19 pandemic, various demands from people for space have emerged. Therefore, this research progressed through a systematic literature review to reflect the trend of research that could provide a new phase in future studies. The performed review assists in establishing a convergent academic direction based on the proposed framework for new decision-making systems.

The developed framework should be introduced academically and practically into the industry. It could be actively utilized by construction practitioners in real projects by increasing the realism and immersion in the technology. Also, building a data repository could allow researchers to obtain and utilize data about people's preferred spaces according to their temperament and psycho-physiologic state. Therefore, the findings of this review study provide comprehensive and valuable insights for supporting personalized indoor design decision-making systems. It secured all social, commercial, and academic values through the proposal of new standards and the integration of mass journal data; and carried out an eco-friendly and human-friendly approach. A conceptual framework that helps various stakeholders prepare for the situation after COVID-19 in advance will be a useful tool for constructing a people-centered indoor space.

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