MDPI

Article

Design Thinking in Lighting Design to Meet User Needs

Kamil Kubiak

Lighting Technology Division, Electrical Power Engineering Institute, Warsaw University of Technology, 75 Koszykowa St., 00-662 Warsaw, Poland; kamil.kubiak@pw.edu.pl

Abstract: In the age of noticing the adverse effects of our activities on the climate, we pay more and more attention to designing sustainable solutions. Assumptions made during such sustainable designs often do not fulfil user needs. Therefore, we frequently encounter discrepancies, such as higher energy consumption and user modifications in the building systems compared to the design and use stages. To mitigate these problems in the lighting design context, the author describes the proposed lighting design method based on the Design Thinking methodology and concerns the commonly applied basic lighting design process. As an example design, an office room interior and lighting design are presented using the Design Thinking method described by the author. The utilised method allowed us to learn about problems that are only sometimes typical for offices and enter them into the design scope. The article contains a detailed analysis and comparison of normative requirements with users' needs, collected from four room users and six guests. The discrepancies between the sustainable design and use stages presented in the article can be considered reduced, and users' interference in the operation of devices will be eliminated due to meeting users' needs and thus achieving sustainable goals.

Keywords: interior lighting; lighting technology; lighting design; design thinking; sustainable design

1. Introduction

In the age of noticing the adverse effects of our economic and social activities on the climate, we pay more and more attention to designing sustainable solutions [1]. The World Business Council for Sustainable Development states that buildings are responsible for at least 40% of energy use in many countries. Lighting accounts for 20–25% of the total electrical use in buildings [2,3]. Worldwide building energy consumption is expected to grow by 45% over the next 20 years [4]. To mitigate this adverse trend, we create various systems that encourage the design of such solutions and try to verify the designs made to meet sustainable design requirements [5]. For example, in 2002, the Energy Performance Building Directive (EPBD) announced new regulatory conditions for all EU countries to decrease the energy needed for heating, cooling, ventilation, and lighting in buildings. Similar LEED-certified (Leadership in Energy and Environmental Design) buildings act in such a way. However, each design requires many decisions and design assumptions. The adopted assumptions seem correct based on the designer's knowledge, applicable standards and regulations, and good practice. However, these standard assumptions sometimes do not fulfil user comfort and satisfaction [6,7]. Because people spend most of their time in buildings and interact with building systems to reach desired comfort, these interactions lead to different energy usage [8–11]. The impact of user actions on various systems, including cooling, heating, etc., has been tested many times [12–14]. For example, energy-efficiency behaviours account for 37% of the variance in electricity consumption between dwellings [5]. Therefore, we observe discrepancies between what we thought we designed and what we designed [12,15–26]. Those discrepancies are more significant for low-energy buildings with more passive design features [27–29]. These discrepancies are the user's emergence and activity; in the literature, it is known as occupant behaviour (OB) [8,11,30–35]. Attempts are being made to reduce this discrepancy and

uncertainty [35–38]. Although the user can be specified, it is individual, unusual, and unique [16,39–44]. Many models have been developed to describe the interaction of users with energy-consuming systems, but they are not sufficient [15–17,30,32,35–37,40,41,43–46]. The failure to understand users leads to various consequences, among which the use of the designed device can be mentioned. The developed device's different services cause other effects and results [15]. These consequences may be, for example, electricity consumption, which directly indicates the level of energy efficiency and the assigned certificates, points, etc. Hirst and Goeltz [44] found that less energy was saved than was predicted by an audit.

In every design process, we always have the designer on the one hand and the user on the other. The user waits for a design and has a specific need or problem to be solved. Using his knowledge, standards, and experience, the designer has to optimally solve this need or problem. Standard, precise, repeatable design solutions proposed by designers are becoming less and less sufficient [26,45,47–49]. People and their problems are not as repetitive and predictive as designers believe, and technology might not be used as designers intended [50]. Therefore, there is a field for methods of supporting the design process that will allow reconciling the point of view of the designer and the user. Also, due to the increased awareness of users and the complexity of design undertakings, the need for mutual communication between designer and user, including dialogue, is constantly growing [26,28,45,47–49,51]. Communication is crucial not only in the designer-user relationship but also within the design team. In such a way, "designers are partners with the problem owners" [52]. Users' knowledge helps them to look at the problem differently, generating various designs and concepts for the design team [42]. These led us to move from technology-centred to user-centred methods [53]. Marcolino et al. claim that the early stage of design decision-making significantly impacts the energy consumption of buildings [15]. Thanks to such reconciliation between the parties, the proposed and implemented solutions will be entirely accepted and fully used by the user [54,55]. The user will not experience difficulties in operating and understanding the solution. The user will use all functions of a given solution and, therefore, energy will be consumed as designed. Otherwise, when the user is dissatisfied with the solution and his environment, changes will be made in the system; for example, Reinhart and Voss [56] reported that in 88% of attempts to close the blinds automatically, the users override the control algorithm. Nicol and Humphreys [57] noted, "If a change occurs, such as to produce discomfort, people react in ways to restore their comfort". There is evidence that tailoring the design of a building's elements and systems around occupants may reduce the energy consumption of buildings and increase occupant satisfaction [2,58]. User-centred design (UCD), participatory design (PD), usability engineering (UE), and user experience design (UX) are practical approaches to improving designs based on end-users' needs [42,59]. It is already known that lighting is a significant factor influencing occupants' performance in indoor environments and other aspects [60]. Therefore, lighting will be the scope of the article. So, it is crucial to design lighting in the manner mentioned above.

This article presents the adaptation of the Design Thinking tool for lighting design, based on the example of office lighting, as a tool for designing around users and their needs. The versatility and transparency of this method can ensure its success in lighting design, as is the case in other areas [61–66]. According to the author, this will reduce the discrepancy and uncertainty between the assumptions in the design and actual use, which are linked to energy consumption. Thanks to this approach, we will also experience less user interference in the lighting equipment and its functioning due to dissatisfaction. Thus, we could reduce energy consumption for lighting, which is around 1/6 to 1/5 of worldwide electricity production [67].

2. Methods

2.1. Design Thinking Approach to Design

Design Thinking is a method of creative problem-solving and a tool for creating new products and innovative solutions based on a broad understanding of the problems

and needs of users. Tim Brown, CEO of IDEO, presented the most accurate definitions of this method: "Design thinking begins with skills designers have learned over many decades in their quest to match human needs with available technical resources within the practical constraints of business" [62,63]. In Design Thinking, users and stakeholders are involved in the design process from the beginning. Design teams are composed of people with different competencies and roles. Considering people's uniqueness, there is a potential for innovative solutions because they are not standard but individual, unusual, and unrepeatable [65]. This was the reason for the creation of this method in the 1980s and 1990s at Stanford University in California: a need to transfer creative and innovative ideas to the Silicon Valley business world. This trend is still valid worldwide.

Design Thinking is, therefore, the design process, with the main goal of meeting the needs of future users of the designed solution [68–75]. However, for the fulfilment of these needs to be feasible, it must be ensured that the effects obtained using this method are cost-effective, innovative, and technologically feasible [76,77].

Therefore, the main assumptions of the Design Thinking method are:

- focusing on the user;
- creatively looking at the problem from different perspectives;
- prototyping and testing solutions to check the correctness of design.

Due to the universality of Design Thinking, it can be used to solve problems wherever there is no one obvious solution. Such issues happen in engineering, e.g., lighting design. The problems we face in lighting also require a combination of different competencies, i.e., technology, design, business, physiology, or psychology. Considering the above, the potential of the Design Thinking method in lighting design is justified. To sum up, Design Thinking can be used when designing lighting that considers users' needs.

Every design is different, but some general activities are common. The Design Council has developed the 'Double Diamond' model to illustrate this (Figure 1) [78]. The model is divided into four phases: Discover, Define, Develop and Deliver. It maps how the design process passes from points where thinking and possibilities are as broad as possible to situations where they are deliberately narrowed down and focused on distinct objectives (see the vertical extent in Figure 1). We can adopt the 'Double Diamond' model in our lighting design field.
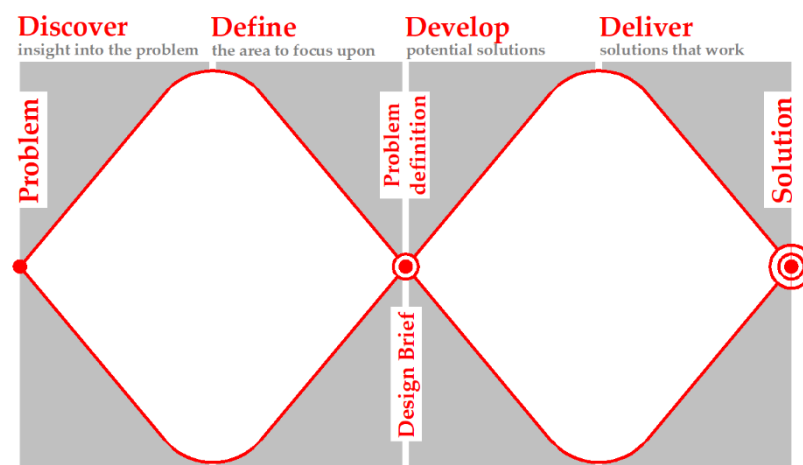

Figure 1. Design Council double diamond model [78].

The double diamond, in more detail, looks as follows (Figure 2a): The Discover phase (the start of a project when the initial problem is known) is a period of discovery, gathering inspiration and insights, identifying user needs, and developing initial ideas for designing a solution to a problem. After that is the Define phase, in which designers try to make a clear brief that frames the fundamental design challenge that constitutes an actual problem. After having a design brief, we move to the Develop period, where we develop solutions

and make prototypes and tests. Each is iterated and constitutes a process of trial and error to help designers improve and refine their ideas. The final part of the double diamond model is the Deliver phase, where the resulting product or service (working solution) is finalised and launched. The whole process is iterative, and each stage is also iterative. Each iteration aims to move closer to the final solution [78].
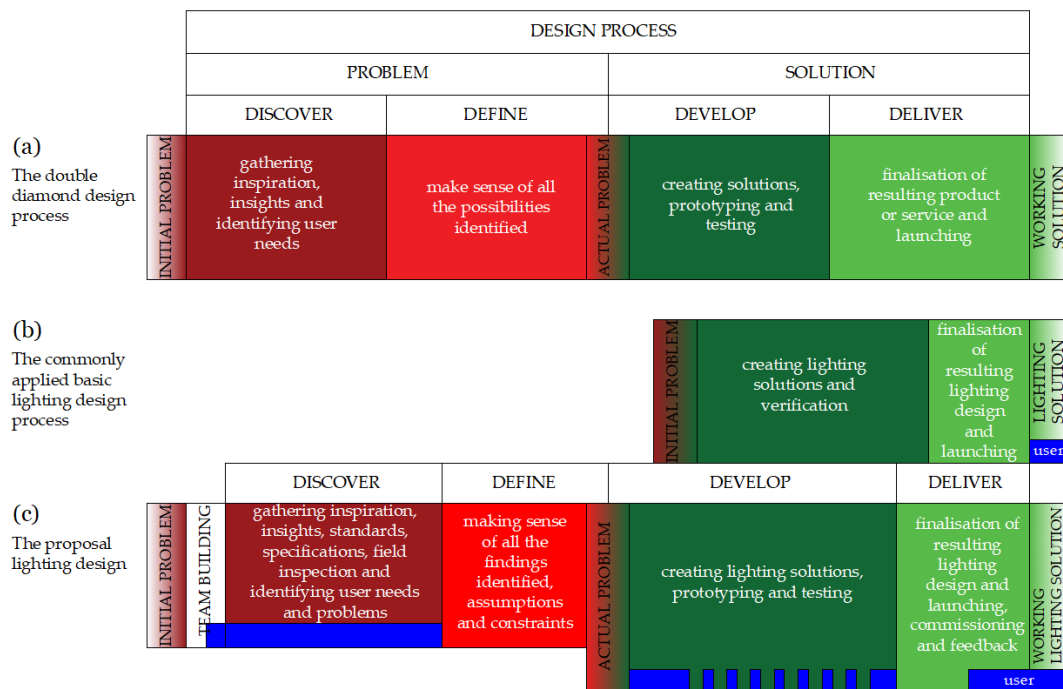

Figure 2. Design process models.

2.2. The Commonly Applied Basic Lighting Design Process

Poland's commonly applied basic lighting design process in a new or modernised facility is similar. It is a part of the entire facility design process related to the electrical installation design. The design office designs independently or by order, and an external company carries out a lighting design based on the technical documentation of the facility and the architectural concept. The electrician, architect, and supervisors then verify that the lighting design proposal presented by the lighting designer meets the requirements. If the conditions are not met, corrections are made. After the final acceptance of the concept, the lighting design, which constitutes the lighting solution, is attached to the facility design and forwarded for implementation. (Figure 2b).

The basis for implementing a lighting solution is the law that imposes the obligation to provide the facility with a lighting installation, e.g., to ensure lighting conditions in the event of a mains power failure, and the specifications of a given project [79,80]. An additional aspect often emphasised is the energy efficiency of the lighting solution [5,81]. The above is an initial problem that the designed lighting intends to solve (Figure 2b).

To find a solution to this problem, the lighting designer takes into account, in addition to the appropriate lighting standard and applicable normative acts, the architect's requirements. However, relevant standards [79] usually give the limit values of lighting parameters without considering whether the values of the lighting parameters fit into a given situation. Moreover, when creating designs, it is often overlooked that lighting is not to be used only as a technical (as for electricians) and decorative (as for architects) element but as one of the elements enabling the proper functioning of the people who use it. As a result, it is forgotten that each user reacts differently to the lighting conditions defined by the designer and has different lighting needs. We can see it in the example of the selection of the colour temperature of light sources. Some people prefer a given room to be lit with a cold colour temperature, and others prefer a warmer one. Such differences in preferences

apply to each of the defined lighting parameters. So, when we look at lighting design from the perspective of users' needs, we are faced with a challenge in terms of design. It becomes insufficient to design solutions by a small group of specialists in a given field, who often base design decisions solely on their experience, proven solutions, and habits. Moreover, the constant change in market trends is in opposition to the craftsmanship that the designer achieves. Also, users' attitudes that question solutions that do not suit them based on the knowledge gathered from various sources due to free access to unlimited information deepen the situation. So, an excellent way to deal with the problem is to include its future users in the design process. Therefore, it is vital to consider specifications, legal aspects such as standards, and actual user needs, whether interior lighting or road lighting. We can achieve this effect by basing the design process on the Design Thinking method.

The lack of such an approach currently being used results from the nature of the entire design process, which is characterised by high complexity [82]. Therefore, all optional elements are eliminated, i.e., they do not lead to significant errors or omissions that could cause failures, damages, and legal disputes. Failure to meet the user's needs in a given case has no direct or negative consequences. This fact should be considered regarding user comfort and work efficiency, which are complex to assess and ambiguous during design and at the facility's start-up time. Each person is also subject to the process of adaptation to the prevailing conditions. Nevertheless, this leads to adverse effects in the long run. Moreover, outdoor lighting is not generally treated in such a way that its selection and operation can be influenced. Even simply turning the lighting on/off translates directly into the working conditions and energy consumption.

Many people are involved in the design process, from identifying the initial problem to implementing the final lighting solution. These include lighting designers, architects, industry designers, investors, contractors, and users. The presence of these people in the process, the activities performed, and the moment of their action vary. From the perspective of the subject of this article, what is significant about this commonly applied basic lighting design process is that the user appears only at the end of the entire process (Figure 2b). This is the moment when the lighting solution is already implemented (made, installed, and launched). After entering the facility and starting work, the user needs to change the lighting setting, e.g., due to the approaching dusk. They also become familiar with this solution and learn how to use it. Unfortunately, due to the designer's lack of knowledge of the actual problem, there is a real risk that the lighting, due to its parameters or their selection via the control interface, will not allow for the creation of lighting conditions convenient for a given person, taking into account their preferences and needs. An attempt to "repair" this lighting will lead to various actions, e.g., changing the workstation, purchasing an additional desk lamp, constantly closing the blinds, turning off or covering luminaires that cause glare, having disputes with neighbours about the lighting settings, etc. All this constitutes the problem described in the introduction, which translates into different, often higher energy consumption than assumed in the design, user modifications in the lighting system, and, in general, discrepancies between the design and the usage of the installation, in this case, the lighting installation. This article proposes a solution to this problem, which will be described in the next chapter as a proposal for a lighting design method.

2.3. The Proposal Lighting Design

Considering the lighting design process and its characteristic features described above in the commonly applied basic lighting design process section, a proposal can be made to modify this process. The modifications will aim to eliminate the problems described above. To achieve this, the Design Thinking design tool will be utilised. So, the lighting design process will now be presented as a modification of the currently used process using the Design Thinking methodology (Figure 2c). Industry organisations bringing together lighting designers, such as the Illuminating Engineering Society (IES), the International Association of Lighting Designers, or the Professional Lighting Designers' Association (PLDA), promote

the design process in their works, courses for designers, and materials that have features in common with the one proposed by the author. However, a different methodology was used in this work based on Design Thinking, and the resulting differences in approach concern, among others, deep consideration of the end users of the lighting solution.

As before, the reason for implementing a lighting project will also be the applicable law and specifications of a given project and, of course, the energy efficiency of the solution. This will be an initial problem. However, when solving this problem, a lighting designer will consider the appropriate lighting standards, applicable normative acts, and the architect's requirements, specifications, and experience. He will act in a slightly different way and will take action to find out the actual problem.

Initially, a design team of the previously mentioned people is appointed, i.e., a lighting designer, architect, industry designer, investor, and contractor. In addition, the design team will be joined by people such as exemplary users, people responsible for maintaining the lighting installation, specialists in the physiology of vision, and any other people with competencies in the field of lighting design, its impact on humans, and who use, manage, and maintain the lighting installation. Then, a critical stage begins, distinguishing the proposed lighting design process from the currently used one.

First stage—Discover

The first stage that starts the entire process is the Discover stage. This stage is one of the most critical stages of the Design Thinking method. It aims to reach future users of the lighting installation to learn about their needs and actual problems. Various internal, external, individual, and contextual factors influence users' behaviour in a space. Therefore, it is necessary to study them in a multi-disciplinary manner to incorporate many elements such as sociology, psychology, economics, engineering, and design perspectives [9,12,16,83]. To avoid this ambiguity, a good way is to reach future lighting users and examine them in the context of lighting. Such an approach is proposed in this article.

Nowadays, a common practice for many lighting designers is to create solutions based solely on standards, applicable normative acts, specifications, and their own experience, and to define a given problem subjectively [34,40]. Lighting and its performance are strongly associated with users using it individually [47,84,85]. Therefore, when developing solutions with this method, the first stage will be conducting observations, talks, or surveys with users to get to know the actual problem. The result of this stage should be a thorough understanding of the user for whom the final solution is being created. It would help look at the world from the perspective of those that will ultimately use designed lighting. The lighting designer, therefore, will know how the client might be tempted to alter the design and will be more successful in meeting the client's needs [40]. This is a challenging task.

First, it is essential for the lighting designer to observe the users for whom lighting will be designed in their natural environment. Such a method, called in situ observation, offers first-hand evidence of users' behaviour [86]. The lighting designer's observations should examine users' lighting preferences at different times of the day. It is worth paying attention to whether, for example, a given user chooses to work with electric lighting or natural lighting in the morning when starting the day. One should also monitor if the light does not cause glare and the associated feeling of tiredness and sleepiness. The lighting designer should also acquire some subjective impressions and feelings. Thanks to this, he can determine what lighting elements are missing from his perspective. For example, we can sometimes observe that a luminaire is covered with cardboard, so it does not shine on a projector screen. These activities directly prove unrealised lighting needs. Carrying out these activities with the people using the space allows us to obtain information about their life, disposition, age, feelings about the existing lighting installation, and the nature of their work or the time spent in the space during the day. It is critical to determine what level of illuminance, colour, or illumination uniformity users prefer. We should find out their needs regarding the type of lighting—whether they prefer general lighting or maybe localised lighting directly aimed at their workplace. The entire stage allows us to learn about users' needs, features, opinions, and current ways of dealing with lighting. The

above activities can be performed most easily in lighting modernisation. However, in the case of new investments, we do not always have access to future users.

Next, we must conduct interview surveys [12,27,66,86–88]. Because of user behaviour diversity, we need an adequate sample to represent the survey population [56,89,90]. During such tasks, both standard and nonstandard users are essential. Nonstandard users allow us to obtain information that we do not even know. Such a user can be a cleaning service person. Although such a person only stays in this area occasionally, he performs essential user activities. In conclusion, we want to find out what the problem is here. This is not only necessary from the perspective of the investor and architect but also, and perhaps mainly, from the perspective of the future user of the lighting installation.

We have many tools that can be used at this stage, for example [76–78]:

- Safari service—an experience of the designed lighting environment by the lighting designer himself. The designer collects information about lighting, uses it, and records his feelings and observations. This activity enables one to understand lighting from the user's point of view, thus raising awareness of strengths and weaknesses.
- User shadowing—the lighting designer observes the user and his environment while using lighting. The observation aims to gather as much knowledge as possible about users' needs and understand their behaviour.
- Interview surveys—personal interview surveys are used to test the user's responses and simultaneously to notice his behaviour.
- The "5 × WHY" technique allows for determining the cause (source) of specific user needs. It examines cause-and-effect relationships leading to the heart of a given problem by asking questions that begin with "Why". This method is also helpful in other stages.

Second stage—Define

In this stage, we need to define the problem that needs to be solved. Following the previous stage, we analyse the responses and observations obtained during the first stage (Discover). In this analysis and synthesis, it is recommended that methods and techniques such as those suggested by Ideo [91] and Stanford [92] be used. It all constitutes essential information. With the help of this information, we can check whether the reason for designing the lighting installation presented at the beginning of the process covers actual problems relating to future lighting users. We should answer the question of what the user exactly needs. How can these requirements be met? It is worth remembering that specific needs are searched for at this stage, not solutions to the problem.

In the second stage, the previously defined problem might appear differently than it is. For example, the initial problem may be changing the layout and luminaires to achieve a transparent effect in a room [93]. After we have asked users in the first stage what they think is causing this lack of transparency, and within different answers, it may turn out that the problem does not lie with lighting and is generated, for example, by the wrong arrangement of office furniture or the lack of access to windows. In this situation, there is a need to redefine the design problem and return to the first stage (Discover), focusing on the need for more access to natural light or furniture arrangement. The multiple redefinitions of the design issue are also the basis of the Design Thinking method. This approach gives the lighting designer the confidence to meet the actual needs of users—not his own. Thanks to such redefinitions, the newly formulated problem fully defines what needs to be done and what the user needs. Therefore, the expressed problem is likely concerning lighting and other aspects, e.g., furniture arrangement, which should be considered in the design (wider solution part of the diagram in Figure 2c). We can then approach lighting design holistically, combining the lighting system's design with other systems. The proper definition of the problem will allow the design of a lighting system that users will ultimately use without any further alterations and with designed energy consumption.

As in the case of the Discover stage, various techniques can be used to define the problem. We may use here [76–78]:

- Empathy map—a way to profile users. Most often, it is made in a diagram divided into six areas. Each area answers different questions: What does the user think and feel? What does the user see? What does the user hear? What does the user say and do? What are the fears and frustrations of the user? What are the needs?
- Creating a persona—creating a non-existent character treated as a representative or archetype of the user group for which the lighting solution is being created through his actions and approach [54].
- Problem mapping—allows us to create an initial outline of its solution by establishing:
  - the owner of the problem, i.e., who the problem concerns;
  - the sources of the problem, i.e., where the problem came from, what are its causes;
  - the symptoms of the problem, i.e., how do you know about the issue;
  - support, or how we can help to solve a given issue.

Third stage—Develop

Having a correctly defined problem, we can move on to creating potential solutions to the problem, which have our user (persona). As is well known, any technical issue can be solved in many ways. The Develop stage is about presenting possible solutions from very different perspectives. This stage occurs in groups and consists of generating as many ideas as possible for solving a defined problem and selecting the best one for implementation according to cost-effectiveness, technological feasibility, sustainability, etc. [54,88]. Ensuring various participants in this stage [31,42,54,94,95] is crucial. Therefore, the Design Thinking method assumes working on a project in interdisciplinary teams. The participation of lighting engineers or architects is essential, but there are also people with little in common with lighting design, e.g., the user or even such people as the cleaning and maintenance service. This allows us to create new and unconventional ideas and, thus, innovative designs aligned with Design Thinking.

The brainstorming method here is recommended and often used in business [78]. Thanks to this technique, each person participating in the project can provide their ideas and develop other people's ideas. However, it should be remembered that, like any technique, brainstorming has specific laws. Compliance with these laws is crucial to achieving the intended goal. The basic principle of brainstorming is knowing that every idea is good. No statement should be criticised—it can be modified to be as creative as possible. In addition, this stage should result in many ideas—a small number will not lead to an optimal solution. Finally, the design team democratically selects the best concepts according to defined criteria, and we can go further on their basis.

However, before implementation, it is essential to prototype the selected solution. The key is to present the solution to the user as soon as possible to verify the design and obtain feedback. When it turns out that we made a mistake in the previous stages, we save time and money on its correction. Regardless of the final result of the work, the prototype must have certain features: be low-budget, simple, and time-saving, and be as close as possible to the target solution [76–78]. It can be a visualisation from a lighting design program such as DIALux or Relux, as often happens when consulting the proposed lighting solutions with the architect and investor. The role of virtual and augmented reality is gradually increasing, which allows us to see the designed space after putting on special glasses [96–100]. Thanks to this, we can present the room model, luminaires, and their arrangement, and most importantly, we can show the visualisation of the lighting effect. However, a prototype can also be used in field trials or demonstration designs, where it is possible to present solutions that can become part of the final design. In lighting design, physical models, such as mock-ups or technical drawings, will not meet their assumptions because it is difficult for users to visualise lighting effects. It is essential that the user can see and imagine what his future lighting will look like.

Immediately after the prototype is made, it is presented to the users, and we ask them for their opinions. This allows for verifying the fulfilment of the needs they define. During tests, it is necessary to explain the operation of the lighting installation. When

the user is watching or trying out the effect of the work, we listen to his opinion and ask questions that will help improve the final result. We should refrain from resolving or undermining users' choices during the talks. The created lighting serves the users and cannot be based on the impressions of third parties. We should give them the freedom to get to know the solution and express their opinion. After performing the tests, the comments received from the users should be considered. Testing makes it possible to check whether the entire process has been carried out correctly and whether the users will be satisfied with the final lighting solution. It is crucial to determine whether the solution meets their requirements and what changes should be introduced. The prototype must be improved until the users are satisfied with it. This stage guarantees that users will fully use the selected and implemented lighting concepts as designed. Therefore, there will be limited discrepancies between what we have developed and what we have obtained, and interaction with building systems to reach the user's desired comfort will be limited. Finally, energy consumption will be as determined [12,15–26].

Fourth stage—Deliver

Only when the user's opinion is satisfactory can we proceed to the last stage—design delivery. During this stage, final design documentation is created. Then the documentation is sent for implementation. After the entire lighting installation is completed following the design, it is launched by the contractor. At this point, all lighting location adjustments are made, and parameters are set in the controllers. Then, after the entire interior is finished and the user moves in, there is an essential time during which the user is familiarised with the lighting installation. The operation of the entire installation, control system, and possibilities are presented. In addition, the user is informed of how the lighting installation works, for what purpose, and why. After some time, when the user gains experience using the lighting installation, the feedback phase begins. The user then shares his observations about the operation and service of the lighting installation. This is when corrections can be made, e.g., the orientation of luminaires and control parameters. Only after such a series of actions can we be sure that the lighting installation will work as it should, meet users' needs, and work optimally.

To summarise, the lighting design process presented using Design Thinking stages should be carried out considering that they benefit users (personas). Therefore, the user participates in many project stages (Figure 2c). In each part of the work, one should deviate from the usual patterns and approach the defined problem as creatively as possible. Doing all the stages one by one does not guarantee success, and we may need to go back to one of the previous stages. The stages of creating lighting using the discussed method can be compared to the closed circle shown in Figure 3. The design team moves along this circle, creating an increasingly innovative solution to a given problem.
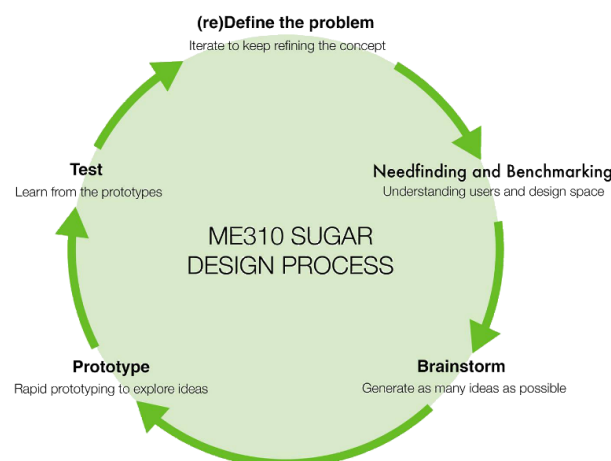

Figure 3. Design Thinking stages and their sequence based on the ME310 Sugar Design Process at Aalto University, Finland.

3. Procedure and Results

The problem that this article is about is the frequently encountered discrepancies between the design and the use of the lighting installation in a building, manifested, in particular, by different, often higher, energy consumption during the use of a building than what was assumed in its design and user modifications to the system during its use.

The author proposes using the Design Thinking method when making lighting designs to solve the above problem in the lighting area. The general form of the Design Thinking method has been described. It describes how lighting designs are carried out and why changes should be introduced. On this basis, the author modified the lighting design process currently in use using the Design Thinking method.

Since the proposed approach to lighting design following the Design Thinking method and its use in lighting design have yet to be described in the scientific literature, this chapter will present an office room whose interior and lighting will be the subject of a project according to the described method. Due to the study nature of the project, not all stages of the process shown in Figure 2c will be used. Nevertheless, it will allow us to draw several valuable conclusions.

The office room for which the lighting design will be developed has the shape of a cuboid 5 m long, 6 m wide, and 3 m high. The room has a suspended ceiling with recessed luminaires and access to four windows with blinds. There are four workstations and five wardrobes in the room. The floor in the room is covered with a grey fabric carpet, and the walls are white. The office room is currently very untidy—it has not been renovated for over 15 years, and the walls and carpet are significantly dirty. Figure 4 shows exemplary photos of the room.
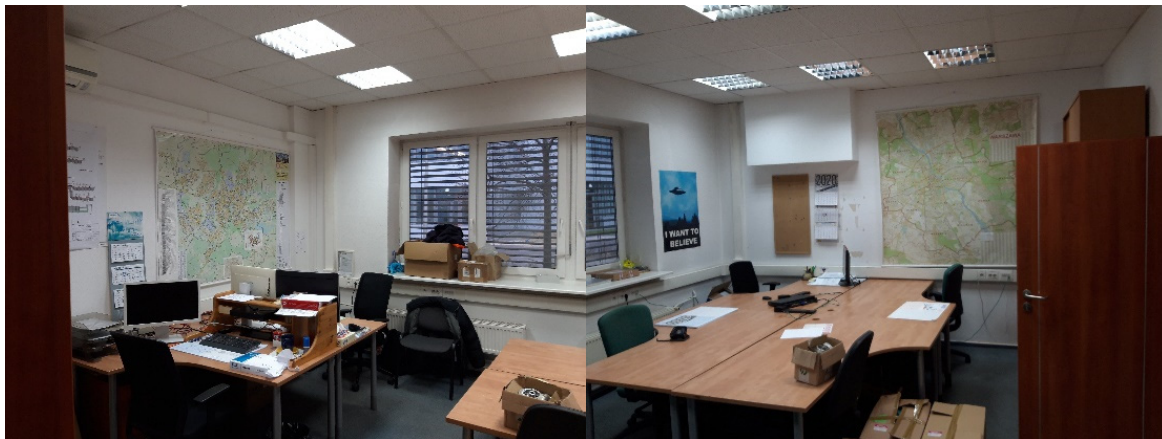

Figure 4. Photos showing the interior of an office room.

The existing lighting installation in the room consists of nine identical raster luminaires with linear fluorescent lamps with electromagnetic ballasts recessed in the suspended ceiling. There is no lighting control system in the room. All luminaires are manually turned on simultaneously. It is also worth noting that the lighting installation has not been changed or renovated since the building was built.

In terms of energy, annual electricity consumption should be determined. However, we need to estimate the expected annual electricity consumption if we do not have actual electricity measurements throughout the year. For this purpose, the installed lighting power in the room should be determined (1). It is based on the following audit:

$$P_i = \text{quantity of lamps in luminaire·power of one lamp·quantity of luminaires}$$
$$+ \text{quantity of ballasts·power of one balast}$$

$$P_i = 4 \cdot 18 \cdot 9 + 18 \cdot 10 = 828 \text{ W} \tag{1}$$

Then, we need to assume the operating time of the installation throughout the year. The lighting can only be turned on completely, making calculations easier. For office rooms, their use is assumed to be 2250 h per year [81]. Hence, the annual electricity consumption will be (2):

$$E = 0.828 \cdot 2250 = 1863 \text{ kWh/y}, \tag{2}$$

The above level of electricity consumption per year is only an estimate. We need to know how users use lighting to get closer to the actual value. The Design Thinking method can also be used for this purpose.

The primary users of the office are office workers working at computer stations—a total of four people. Employees from other rooms and company buildings also occasionally appear in the room. The nature of the work performed in the room can be considered mental work.

Initial problem—the office room has not been renovated for over 15 years, and therefore, the manager plans to modernise (1 to 1) the lighting and refresh the room (paint the walls and ceiling). The manager will do this without the informing or consulting with employees (room users). He will commission an electric company that he is familiar with to perform the work.

In addition to the lighting designer, architect, electrical installation designer, and company owner, the design team also included a representative of the contractor, four regular users, six people visiting the room, a room service technician, and a person from the cleaning service.

The Design Thinking method research tools presented in the described lighting project will only serve as an example. Their purpose will be to enable the designer to learn about the lighting needs and preferences of the users of the designed lighting. As a result, it is expected that the problems mentioned in this article will be reduced.

3.1. First Stage—Discover

According to the method description in Section 2.3, the designer will first become acquainted with the space covered by the design and its users. An exemplary research tool called user shadowing and service safari will be used for this purpose.

The user shadowing method was the first used when working with the respondents. The idea of this tool is to observe users while using the product—in this case, the lighting available in the room—without interfering with their behaviour. During the designer's several visits to the room, two research groups were selected among the users. The first group consisted of four employees who stayed in the office room regularly (every day), sitting at their workstations. The second research group consisted of six employees who remained in the room occasionally. Observing their work schedule, it was possible to learn the typical behaviours of people working permanently indoors (the first research group). Of course, each employee has a slightly different action plan based on the tasks assigned, depending on the day. Despite this, some similarities were noticed during the observations.

In terms of room lighting, a fascinating situation was noticed. On a sunny summer day in the office, almost all the blinds were closed, and the electric lighting was on all day. All lighting was turned on, allowing for the completeness of the installation to be checked. Two fluorescent lamps in one luminaire were not working correctly—flashing periodically. This caused repeated irritated glances from users in this direction. Also, during the lunch break, the lighting remained on when users went to the canteen together. A similar situation always occurred among people visiting the room. They were wondering where they could sit and talk to the room's workers. Finding a place to do the work was challenging when there was a need to display materials on a computer screen. In the case of remote presentations, users used a webcam but with a background, often depicting the attractive interior of a modern office. It was noticed that the room's users changed their positions in their armchairs very frequently, especially in the afternoon. Employees adopted various sitting positions—from upright to hunched.

The next tool used at this stage was the Safari service method. In this case, the lighting designer took on the role of the room's user and had the opportunity to better understand all the behaviours, impressions, and interactions with the light in the room that he had previously observed. He was able to spot additional issues that he might not have seen when watching users as a third party. During two full days of work in the room, the designer occupied two characteristic workplaces, one for each day, each located differently around the windows. Together with the regular users of the room, he fulfilled similar duties and tried to behave similarly. Thanks to this, he could feel like a user of the room, which allowed him to examine what, in his opinion, the respondents' needs were and how they could be satisfied. Of course, the observations and feelings were subjective, but they provided another layer of information necessary for the design. The first thing the designer noticed was the pollution of the room, poor technical condition, and mess, e.g., documents in various places. By working in different areas of the room, the designer could learn about the lighting conditions on a sunny day. Opening the blinds at workstations with the monitor facing the window made working impossible. The luminance contrast between the exposed windows and the monitor in their background was too high for a visually comfortable position in places facing opposite directions.

Based on the two previously presented methods, the designer had the opportunity not only to get acquainted with the environment for which he will be carrying out the project but also to define certain typical behaviours and reactions specific to a given interior and its users and certain situations occurring in the room. The next step in understanding users' needs is to learn about their opinions, emotions, and motivations. The following research tool was used to obtain such information: user interviews [86].

Interviews were conducted with everyone employed by the company that stays in the room regularly (4 persons) and stays there occasionally (6 persons). The research was performed individually, i.e., one researcher + one subject, in the room being the subject of the study. The duration of the examination for one person was approximately 20 min. After this time, the test person was changed, with one person tested per day. The tests were carried out in a non-invasive way. At the beginning, the subjects agreed to participate in the study. All people were healthy adults (admitted to work based on a medical certificate). The interviews were divided into two parts—the first one concerned general information and was conducted in the form of a questionnaire, completed independently just before starting the second part—the primary interview. The survey asked about age, eyesight condition, position held, seniority, activities performed, and time spent in the designed room. The second part of the interview was conducted in the form of a live conversation. The person who conducted the interview was the moderator and only had an idea of the talk's direction. The interview was conducted as an example conversation scenario using the questions below. During the interviews, the discussion depended mainly on the respondent, and the questions and their order were adapted to the given person and the answer.

1. Are you satisfied with the work you do?
   Why do you get this impression?
   Are these the only reasons?
2. What is your job?
   What tools do you use while working?
3. Are you satisfied with the room in which you work?
   Why are you satisfied/unsatisfied?
4. What does your dream office look like?
   What would you like to have in it?
   Why does such an office meet your expectations?
   What benefits do you see in such an office?
   What would it affect?
5. What do you feel when you are in the room?
   Why do you feel this way?

If it is variable, what does it depend on?
How do your feelings change after leaving the room (during breaks or at the end of the working day)?

6. Do you think you have enough space in the room?
   If yes/no, why do you feel this way?
   What do you think? What influences your feelings?

7. Do you think your workplace is well-lit enough?
   Why do you think so?
   What can you say about the lighting of the entire room?
   How would you like your workplace/room lit?
   Do the blinds fulfil their functions?

8. Do you think there should be daylight in the room?
   Are you satisfied with the amount of daylight in the room?
   Why do you think there should be more/less of it?
   What impact does adequate daylight have on you?

9. How many hours a day is artificial lighting on?
   Does this change throughout the week?
   Does it change with particular seasons?

After collecting user information, the designer familiarised himself with the lighting standard for office interiors [79], applicable normative acts, and the investor's specifications. Moreover, he was inspired by photographs of modern office interior design solutions. All this provided an extensive collection of diverse information that describes the design situation from different perspectives. The order used—user first and then standards and specifications—is purposeful and very important here. Thanks to this, the first image of the situation in the designer's head comes from the user, not the standards. It thus remains permanently in memory, giving this information significance. Therefore, knowing the user's needs, we understand why we should use specific technical means. We know their justification, unlike generalising norms.

Completing the first stage of the Design Thinking method allowed us to collect information about the users, the room, and the interactions. Based on them, it was possible to move to the next stage, after which the users' needs would be determined and the resulting actual design problem, referred to as a design challenge in the Design Thinking method, would be defined.

3.2. Second Stage—Define

After all the interviews with the users and observations, it was crucial to create a user persona. A user persona is a character that embodies all user research in an easily identifiable and understandable form. It brings together lots of information about the users to create a single character that represents the group. In this case, since we have two different groups of users—regular and occasional—there was a need for two personas. Such personas cover name, age, occupation, where they live, family, hobbies and interests, likes and dislikes, and most importantly, needs. Among the persona's information, the most important for the project were those related to interior design and lighting (Table 1).

After analysing all user information using the previously mentioned research tools, it was concluded that the office room should be renovated and refreshed in decor. The identified user needs can be divided into two groups: the first group is the needs related to the new interior design, and the second group is the needs directly associated with replacing the existing lighting installation.

Table 1. Personas representing two groups of room users.

Persona	Profile and Mindset	Needs and Aspirations
Peter (regular user)	He is 30 years old; married. A Service Engineer who stays indoors every day. Satisfied with the work performed and with the opportunities for professional development. Irritated by the condition of the room—dirty, messy.	Opportunity to develop. He needs to have a sense of privacy. Comfortable place at the desk, nice interior, visual comfort. He likes the entrance of daylight into the room. He appreciates the ability to adapt the lighting to current needs and situations.
Anna (occasional user)	She is 40 years old; has a husband and a son. A Service Manager who visits the room more than twice a week. She values her high position and the influence she has in the company. She likes freedom of action.	Ease of communication, exchange of views, discussion, and teamwork. She needs a dedicated place to work in the designed room. She likes the entrance of daylight into the room. She needs good lighting in warm colours throughout the entire space.

The most crucial interior design needs are:

- Furniture replacement—more wardrobes and chests of drawers to store items. Rectangular and slightly larger desktops. Adjustable desks and chairs so the employee can decide in which position he wants to work at a given moment. The furniture has bright colours, but its arrangement requires changes to improve communication between employees while maintaining the sense of privacy provided by the current furniture arrangement.
- Supplementing the room's equipment with furniture, enabling the teamwork of the people working in the room with external users. Additional chairs or a sofa and a table where visitors could work.
- Inserting elements that enable the presentation of work results during internal meetings or client conversations. A magnetic board or TV screen allows employees to share their ideas and projects with other team members more quickly.
- Bringing the room to an aesthetic condition (renovation) that will motivate users to perform everyday tasks.
- Room decor that looks good. Plants, paintings, or photo wallpapers can be added to decorate the room's walls.

The most crucial lighting needs are:

- Changing the light sources in the luminaires—the previously used fluorescent lamps negatively affect concentration and irritate the room's users.
- Changing the colour temperature of light sources—the users claim that the light produced in the room is too cold.
- Introducing a lighting control system with the ability of dimming the luminaires—the respondents who use the room want to influence the lighting conditions in and at their workstations and adapt them to the weather outside the building.
- Changing the type of lighting at workstations—apart from general lighting, employees also need luminaires to illuminate their workstations.
- Illumination of the walls and ceiling.
- Highly durable luminaires (light sources)—employees often request to replace burnt-out fluorescent lamps. Unfortunately, based on their statements, it can be concluded that these requests are very rarely fulfilled.

To create a lighting design using the Design Thinking method, in addition to meeting users' needs (personas) examined at the Discover stage, it is also necessary to consider the parameter values listed in the standard [79] and other applicable normative acts that were not in the scope of this work. Therefore, Table 2 compares the normative lighting criteria with the critical opinions of the users (personas) in the interviews. Then, the resulting parameter values for the design are presented, along with their justification. The designed room was given an area type—CAD workstations, conference rooms, and meeting rooms by [79].

Table 2. Comparison of standard values of lighting parameters with user opinions.

Lighting Parameter	Normative Value	User Opinion, Justification	Value Selected
1. Average illuminance	Task area $\geq$ 500 lx Immediate surrounding area $\geq$ 300 lx Background area $\geq$ 100 lx	Users from the first research group agreed they had enough "amount of light" at their workplaces. The measurements showed a higher level than required by the standard, so the requirements increased.	Task area: $\geq$750 lx Immediate surrounding area: $\geq$500 lx Background area: $\geq$200 lx
2. Lighting uniformity	Task area $\geq$ 0.6 Immediate surrounding area $\geq$ 0.4 Background area $\geq$ 0.1	The measured values are much higher than those recommended in the standard. This requirement has also been increased to match the accepted values.	Task area: $\geq$0.7 Immediate surrounding area: $\geq$0.5 Background area: $\geq$0.2
3. Illuminance and lighting uniformity of other surfaces	Walls: $E_m \geq 150$ lx For offices: $U_o \geq 0.1$ Ceiling: $E_m \geq 100$ lx $U_o \geq 0.1$	Users said the walls and ceiling could have been better lit and wanted everything to be a lighter colour throughout the room. The measurements showed lower values than the norm. Therefore, standard lighting values were used, with the possibility of increasing them.	Walls: $E_m \geq 150$ lx; $U_o \geq 0.1$ Ceiling: $E_m \geq 100$ lx; $U_o \geq 0.1$
4. Average cylindrical illuminance and uniformity	For offices: $E_z \geq 150$ lx $U_o \geq 0.1$	The interviews show that good communication and appearance are essential for employees during meetings. Values at the level specified in the standard will be adopted.	$E_z \geq 150$ lx $U_o \geq 0.1$
5. Modelling	0.3–0.6		0.3–0.6
6. Discomfort glare	$R_{UGL} \leq 19$	The research wants to ensure that on sunny days, natural light does not reflect from computer monitor screens and that artificial light does not significantly dazzle them. The value was reduced from the norm because users during interviews claimed that the lighting bothered them.	$R_{UGL} \leq 16$
7. Colour rendering index	$R_a \geq 80$	In remote and on-site meetings, users want to look attractive. They want the light to reflect their appearance better. Light sources other than fluorescent lamps (LED) with a high R_a value will be used.	$R_a \geq 80$

Table 2. *Cont.*

Lighting Parameter	Normative Value	User Opinion, Justification	Value Selected
8. Correlated colour temperature	There are no specific requirements for the correlated colour temperature value. The value depends on the lighting intensity, interior colours and ambient climate.	According to users, the light in the room is currently too cool; they prefer a warmer light colour. Employees want to be able to adjust the light colour to the time of day and circumstances.	T_{cp} = 3000 K controls
9. Luminance distribution	No specific requirements. Too high and too low luminances and contrasts should be avoided. Light colours for the walls and ceiling are advisable.	Users prefer the white colour of the ceiling and walls, without texture. Luminance from natural light disturbs employees at work. According to the respondents, the room has insufficient light when the windows are covered with blinds.	White colours of the room. Blinds transmit light in a diffused manner with limited luminance.
10. Specific requirements	Work with DSE Controllable lighting	When working with artificial light, light from luminaires reflects off computer screens. They want to be able to control the lighting so that it is sometimes brighter and sometimes darker. The respondents want to choose which luminaire should be lit at a given moment.	$L \leq 3000 \text{ cd/m}^2$, for monitors with $L > 200 \text{ cd/m}^2$
11. Maintenance factor	There are no specific value requirements.	Users do not like the neglected state of the entire room. They claim they too often have to ask the building maintenance service to replace worn-out fluorescent lamps.	Light sources and luminaires that do not require frequent maintenance, $T \geq 50{,}000$ h
12. Energetic efficiency	There are no specific value requirements.	No user opinions.	Ensure energy efficiency.

Based on Table 2, the following conclusions should be drawn: The values of illuminance and uniformity (items 1 and 2 in Table 2) are currently at a higher level than required by the standard. By carrying out the project without knowing the users' needs, these values would be lowered to match the value in the standard. Therefore, user dissatisfaction with "worse" lighting conditions after modernisation would arise. Their work could become less efficient, and thus, they could take action to increase the lighting intensity by, for example, purchasing additional desk lamps and therefore increasing the electricity demand.

Based on the measurements, the intensity and uniformity of the illumination of the walls and ceiling (item 3 in Table 2) turned out to be lower than recommended by the standard. Therefore, the design should include better lighting on these surfaces. This can be achieved by selecting appropriate luminaires and their installation location and using white wall and ceiling surfaces with high reflectances (item 9 in Table 2). The current luminaires built into the suspended ceiling (a standard solution in offices) and textured walls need more lighting, especially the ceiling. Better illumination of the walls will positively impact reducing luminance contrasts under artificial lighting. It will positively minimise glare and improve the quality of work at monitors (items 6, 9, and 10 in Table 2). Glare occurring in the room comes from, among others, windows and their location. The existing blinds do not fulfil their function because, after they are covered to prevent glare in the room, there is too little light, forcing users to turn on artificial light. This completely contradicts the use of natural light. Additionally, existing electric lighting is also perceived as causing glare. When designing new lighting, you need to consider this and use appropriate luminaires so that the URG determined in the room is low (item 6 in Table 2). Therefore, the UGR value was reduced compared to the norm. New blinds must be selected so that on a sunny day, they eliminate excessive luminance in the room and thus illuminate the room sufficiently so that it is not necessary to turn on artificial lighting.

The colour temperature of light in office rooms is often set at 4000 K (item 8 in Table 2), which is currently the case in this room. However, according to the users, the light in the room is presently too cool and makes them feel bad while working. They often mentioned that the light made them feel overstimulated, which led to irritability. A warm light colour will create a calmer and more pleasant working atmosphere in the room. Therefore, warmer light colours, characteristic of places of rest and not intensive work, should be considered. In addition, employees want to be able to adjust the light colour to the time of day and circumstances. This leads to a lighting control system that allows the colour temperature and intensity to be changed (item 10 in Table 2).

The selection of high-quality luminaires and durable light sources is essential to eliminating the current frequent lighting failures and long waits for their repair, which irritate users (item 11 in Table 2).

Energy efficiency is also essential (item 12 in Table 2). The project must ensure the rational use of electricity. Nevertheless, it must be remembered that the actual energy consumption of the designed lighting will result from the equipment and technical solutions used and how users use them. The Design Thinking method ensures that this use stays consistent with the project's assumptions. As a result, the problems addressed in this article are expected to be reduced. However, based on users' observations of the time the lighting is on during the day and clarification of this during interviews, it can be assumed that the room is used on average 9 h a day. During this time, the lighting is on all the time. Even on sunny days, due to the need to cover the windows and reduce the lighting level due to glare, it is necessary to illuminate the room with artificial lighting. In 2022, there were 251 working days in Poland, and assuming an average of 9 h of lighting per day, we obtain 2259 h. Therefore, this value is consistent with the initial estimates. Nine hours of lighting operation per day throughout the year, regardless of the availability of daylight, gives a justified need to improve the functioning of lighting through energy-saving luminaires, appropriate lighting control, and appropriate distribution of daylight into the interior for room lighting instead of artificial lighting.

The initial problem identified at the beginning of the project, consisting of a simple modernisation of outdated lighting (one-to-one replacement) and refreshing the room, can now be confronted with the results of the Define phase. As the above results show, there are several problems in the room, not only related to lighting, which the designer learned through the Discover phase. In this way, there is an opportunity to implement the project in such a way that the needs of future users are met, and they can fully use it following the project. This gives us a chance to reduce the problems this article is concerned with. Therefore, the actual problem will be broader than initially expected.

The actual problem caused by the failure to meet user needs identified in the Define phase must be appropriately defined as a design challenge. This will allow us to continue working on the project through Design Thinking. This will allow for the proper orientation of subsequent activities performed by the project team. Using the recommendations, the design challenge should first of all be formulated in such a way that:

- It is not too general or limiting;
- It focuses on specific users or groups of users;
- It addresses the needs and problems that were revealed in the Discover stage;
- It is designed in such a way that it allows for the creation of various solutions.

Taking the above into account, the following design challenge was identified as a real problem:

"How can we design the decor and lighting of an office room to provide employees and their guests with an environment conducive to the effective fulfilment of daily business duties?"

As we can see, the design challenge, i.e., the actual problem, differs significantly from the initial problem, which was supposed to concern only replacing the lighting with more economical lighting and refreshing the room.

3.3. Third Stage—Develop

This stage aims to create a design that will solve the problem defined at the end of the Define stage. First, ideas for solving the user's (personas) issue will be generated; then, prototypes will be created and tested by users. Ultimately, the final design solution will be made iteratively.

Generating ideas is most often associated with a well-known design tool—brainstorming. In this project, such a tool was used based on the principles of this method. Conducting a creative session with the design team involved presenting potential solutions to the design challenge defined above. From the lighting, it was the choice of luminaires; from the furniture, it was the choice of desks, armchairs, wardrobes, and wall and ceiling finishes. When selecting potential solutions, the need to meet the needs identified in the Define phase was considered. Some solutions were ultimately chosen from the entire pool based on discussion and voting. The selected solutions will then be used to create prototype solutions to the design problem.

Prototyping is another activity in the Design Thinking process. It takes place right after the idea generation stage. Thanks to the created prototypes, the designer can easily and quickly verify whether the solutions developed and selected during idea generation suit a given project.

In this project, three prototypes (from now on referred to as variants) were created. Individual variants are treated as three independent room designs. The variants differ significantly in terms of interior equipment and the selection and arrangement of lighting. For each, details related to the interior design, lighting, and photometric calculations performed to verify the values of individual lighting parameters assumed in Table 2 can be presented. Due to their number, they will not be described in this work. These were the basis for developing variants in terms of lighting and interior design:

- The lighting requirements defined in Table 2, determined by analysing user needs related to lighting and the lighting standard EN 12464-1:2021 [79];
- The defined needs related to room equipment at the Define stage;

- The design solutions are presented at the idea generation stage.

Several variants were chosen so that users could analyse and compare them in detail. This way, we can draw more valuable conclusions. Variant models were made using the lighting design program—Dialux EVO Version 5.12.0.5620. Figure 5 shows one exemplary view of a 3D model for each of the three variants, constituting a prototype. A prototype made in this way allows the user to present the design in the form of realistic photographs or a dynamically changing view using manual control. It is a frequently used lighting design and visualisation tool in the lighting industry. Both designers and users are used to it. Of course, other tools allow us to obtain more realistic models, such as 3ds Max. However, creating models for them is time-consuming and, therefore, expensive, and this is in contradiction with the idea of prototyping, which assumes that the user will be presented with a potential solution to his problem quickly, efficiently, and at low cost. In addition to creating a prototype in lighting design software, field tests were carried out to select the material from which the blinds would be made. The lighting effects that were obtained could not be simulated by a computer, so field tests were conducted.

Figure 5. An exemplary view of a 3D model for each of the three prototype variants.

Testing is a crucial design activity according to the Design Thinking method. Prototypes of the designed solutions are presented to and assessed by the users. This allows us to check whether the course of action adopted by the design team is consistent with what users expect. Sometimes, finding an appropriate solution to the problem took time. Testing conclusions regarding prototypes allows for the efficient selection of the final solution to the design problem. Testing is also another opportunity (after the Discovery stage) to understand the user, interact with him, and build relationships. This is due to observations and conversations, sometimes leading to new comments and conclusions.

Taking into account some good advice, as reported by [47], which should be used to ensure that these activities are carried out correctly, it was decided that testing should take into account:

- Showing the prototype and not talking about it—when presenting the prototype, everything was not explained at once, i.e., the testing person was allowed to interpret what he saw, and the designer had to carefully observe and listen to the user's questions about issues related to the presented prototype;
- Creating the impression of an experience to which the user responds—the user had the opportunity to get to know the prototype in all possible ways, thanks to the dynamic change of the presented view;
- More than one prototype allowed the user to compare them and reveal hidden needs.

The project involves creating a lighting solution and introducing changes to the interior design of the office room. Therefore, it was decided that the testing stage would take place as follows:

1. Discussing with users the conclusions regarding the Discover stage and confirming the needs defined at this stage;
2. Presenting variants (3D models) of the designed room using the Dialux Evo software Version 5.12.0.5620 and making the program available to the respondents, which allowed them to independently rotate the views and thus observe the variants from every possible side; presentation of the luminance distribution in the room and a short instruction on how to understand it;
3. Receiving preliminary comments on each of the three presented prototypes;
4. Explaining to users the solutions used in the prototypes and discussing how they will affect the fulfilment of needs;
5. Writing down each prototype's comments received and its advantages and disadvantages.

The tests were conducted on the same users (10 people) interviewed during the Discover stage. Efforts were made to ensure that the tests were carried out in groups, i.e., more than one user participated at one time. Thanks to this, testing was carried out more efficiently, and at the same time, it was possible to conduct discussions between users themselves and between users and the design team. This allowed the design team to receive many constructive comments and observations, which are the most important at this stage.

The results obtained in the testing phase formed the basis for further action. A survey summarising the tests was conducted after a detailed analysis of the conclusions obtained during the testing stage. The survey consisted of arranging the variants in an order consistent with the preferences of a given respondent—the user numbered the prototypes from 1 to 3, marking the design with 1—the most suitable design, 2—less, or 3—the least meeting his needs. The survey results are graphically presented in Figure 6.
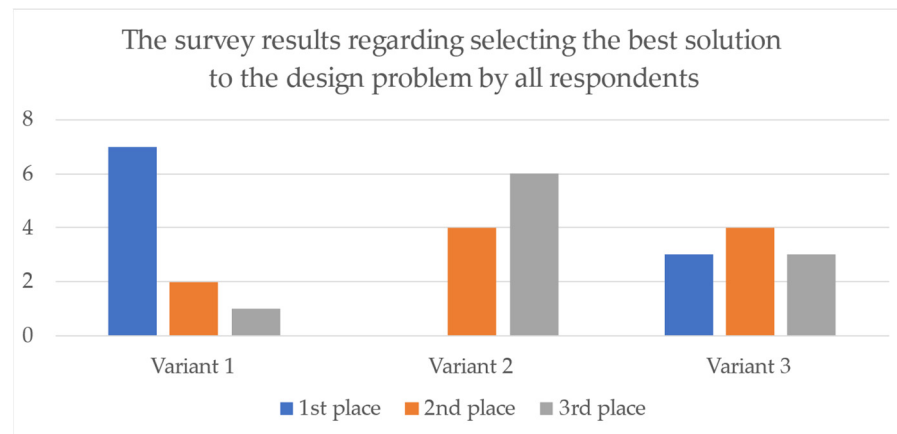
Figure 6. The survey results regarding selecting the best solution to the design problem by all respondents (10 people).

As seen in the chart (Figure 6), variant number I was chosen most often, then variant number III was selected, while the second variant was not chosen as the best. Due to the presence of two characteristic groups of users (regular and occasional), it was decided to check what the results of this test look like for the individual groups. Analysing these results, it turned out that regardless of whether the user is an employee of the room or its guest, variant I is chosen as the best design; however, in the case of type two respondents, variant number III also received the same number of votes. This could be due to the clear separation of the cooperation zone and a more significant amount of space intended for work with guests in variant III, which needed to be added regarding the comments about design I.

Summarising the survey results, variant I was the obvious choice for the best solution to the design problem. However, considering the results obtained in the survey conducted only among guests (the same number of votes for variants I and III), it was worth considering the few advantages of variant III and applying them to the most frequently chosen variant I. Therefore, by adding mobile seats for guests, the design team introduced minor changes in variant I, relating only to the area associated with an additional place for cooperation with visiting room collaborators. Figures 7 and 8 present the final form of the solution to the design problem, i.e., a slightly changed variant I, which considers the respondents' comments obtained during the testing stage.
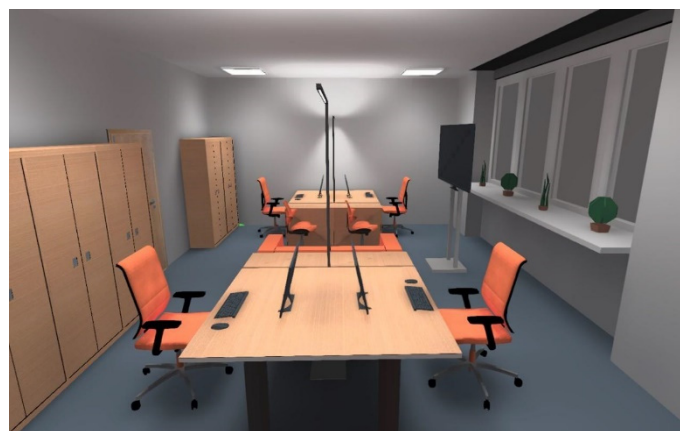

Figure 7. Visualisation of variant I after corrections motivated by user suggestions—view from the right side of the room.
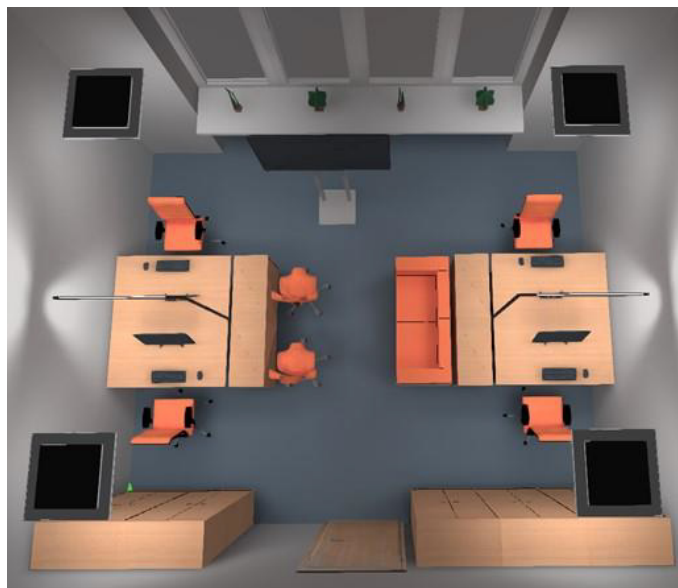
Figure 8. Visualisation of variant I after corrections motivated by user suggestions—top view.

The improved variant I and the unchanged variants II and III were subjected to another survey. As the change was relatively small, the results did not change in the area of selection of regular users of the office room, but this happened in the case of the second group of respondents, i.e., occasional users. Once users accept a solution, they can move on to the next stage.

In terms of energy, the installed lighting power in a room, depending on the number and power of luminaires, is (3):

$$P_i = 4 \cdot 36 + 2 \cdot 69 = 282 \text{ W,} \tag{3}$$

The exact operating time of the lighting installation after the room's modernisation has yet to be discovered. In such a situation, the only savings can be made by reducing the installed lighting power from 828 W to 282 W. This results in an almost 3-fold decrease in power consumption. In addition, there are benefits of automatically turning off the lighting when there are no people in the room, adjusting the lighting level according to current needs, and not turning on the lights on sunny days, thanks to the appropriate introduction of daylight through dedicated blinds. All this has great potential for savings.

3.4. Fourth Stage—Deliver

This stage still needs to be completed as part of the project. The reason was the project's planned completion at the ready documentation stage, awaiting possible implementation. In the case of performing this stage, one would need to follow the steps described in the fourth stage—Deliver in Section 2.3, The Proposal Lighting Design.

To sum up, two critical steps are needed after installing the designed solution. The first one is to adapt the luminaires and the control system to the users' needs, which were determined during work on the project. The second occurs after some time of using the room and assumes making corrections in the installation operation, knowing the users' experience using the facility. Before using the room, there is also a stage of instructing the user on the functioning of the entire installation.

4. Discussion

This article presents the Design Thinking method in lighting design. It aims to minimise the problem of discrepancies between the sustainable design and use of the facility and modifications by users aimed at meeting their needs, which often cause higher energy consumption. Many conclusions can be drawn by analysing the results and experience

gathered during the project described in this article. For clarity, the findings will be divided into individual stages of the Design Thinking method.

First stage—Discover

In the lighting project described, based on the Design Thinking method, exemplary research methods were used to collect information about the users and lighting. Other methods and their combinations may replace the techniques used. It is important to emphasise that more than the methods used are needed. Several methods are essential to getting complete results. They should be applied in the appropriate order so that each subsequent method allows for supplementing or clarifying the information obtained from the previous process. This is what happened in this work. Thanks to this, knowledge about the user increases without complicating the situation. In the case of both user observations (user shadowing), user activities performed by the designer (service safari) and interviews, appropriate user representatives (a representative group) should be selected. A representative group, i.e., one for which the addition of another respondent does not introduce a significant change in the available information. In the case of this project, the situation was convenient because the number of people who came to the room regularly or occasionally was small and could be fully taken into account in the research. When the designer finished using the methods described in this work, he felt that he was no longer learning new things, and what he had learned was starting to repeat itself. In another project, choosing the right people will be a challenge. Being "invisible" to users is difficult with the user shadowing method. There is always a change in some user behaviour due to the observer effect (Hawthorne effect). Users initially felt uncomfortable with the designer's presence, but after a few hours, they got used to it and almost did not notice it. This situation can also be expected in other projects. In the service safari method, the value of which is the confrontation of previous observations from the user shadowing method with the designer's feelings, it is difficult to impersonate the user and behave like him. The designer must be trained by one of the employees about the work performed by the employee. However, the novelty effect always occurs and affects the designer's perception. The designer playing the user role is in a new, uncomfortable position. The designer must focus as much as possible on the task. Therefore, the designer is required to feel comfortable in a new environment. To be effective, the interview (questions) should be prepared based on information from the previous stages, such as user shadowing and service safari. The interview is intended to obtain answers to unclear issues observed by the designer.

Regardless of what they are, the research methods should be described as time-consuming, requiring much commitment on both sides (designer and user), cooperation, user self-awareness, designer research skills, and respondents' selection. All this will affect the results obtained, their quality, and the time spent. In this project, the designer already had basic knowledge and experience about the methods used. Additionally, he had no time limit. However, if the designer needs to gain knowledge and experience, the participation of a Design Thinking moderator in the design team is necessary.

The Discover stage allowed us to learn about several problems that are only sometimes typical for offices. They result from the specificity of the room, including equipment, lighting, and users. The critical problem observed during the project was glare, caused by many factors, including inappropriate window covers.

The Discover stage allows us to learn about user needs in a given situation. Thanks to this, it is possible to meet users' needs with appropriate lighting design and, in this process, keep in mind the goal of sustainable development, which is the rational use of electricity for lighting purposes. This approach is supported by the Design Thinking method.

Second stage—Define

User needs identified in the Discover stage verify whether the initially defined problem resulting from the assumed user needs is reflected in reality. In the described case, the scope of work to be carried out had to be changed (deepened) to consider the researched

user needs. This is how the actual problem arose. This became the starting point for determining the requirements for the project, i.e., selecting specific parameter values (including lighting). The article focused on the lighting side, so Table 2 contains a detailed analysis and comparison of normative requirements with users' needs. This did not happen in the described case, but it can be expected that it will be challenging to establish requirements when users' needs oppose the normative requirements. It can be expected that the requirements will need to be increased or decreased within the range permitted by standards according to users' needs. In this project, there was a need to increase illuminance and lighting uniformity and decrease the UGR value. Such situations may be challenging to implement due to the demand for additional solutions that increase costs and, sometimes, energy consumption. Of course, reducing parameters and, thus, energy consumption would be desirable. Nevertheless, meeting users' needs is crucial for their proper operation. It guarantees that there is no risk of users introducing modifications that may result in an additional increase in energy consumption, e.g., through non-optimal operation of devices. Introducing a reduction in energy consumption due to the design not meeting users' needs will probably lead to modifications that will eliminate the savings achieved in the design. Therefore, implementing sustainable lighting may be illusory, i.e., real only in the design documentation and not reflected in the use of this installation.

The identified actual design problem had to be skilfully described as a design challenge to enable further practical work. It was not a simple matter. This required the intuition and experience of the design team. No need could be omitted because not all needs would be solved.

Third stage—Develop

Correct execution of the Discover and Define phases allowed for rapid progress through prototyping and testing. The changes needed were cosmetic, decreasing with each iteration and converging to the final solution. However, this was an optimistic case. In practice, a long process should be taken into account. It is often the case that we base decisions on our ideas rather than facts.

Knowing the actual problem and having a specific design challenge, it was necessary to present potential solutions and select those that would be implemented. Generating solutions took a lot of work. Knowledge of tools, considering group dynamics, and how to make choices was needed. Even though the diversity of participants was limited, and they were required to comply with the rules entirely, it still caused problems with mutual communication. Some people use a different language depending on their competencies. Moreover, people specialising in a common area tend to find solutions quickly and do not appreciate comments from people outside their area of competence. Despite these difficulties, solutions were selected for implementation. Due to their non-standard nature (innovation), the resulting solutions will often require field tests to verify their usefulness, durability, etc. This was the case in this project, which involved selecting a new method of covering windows instead of the existing blinds. Choosing the degree of dispersion of the light transmitted through the blinds from the available materials was necessary to minimise glare.

The appropriate method for making prototypes needs to be chosen. In this work, the standard form of the prototype, i.e., visualisations, was chosen. Prototypes such as visualisations are a means of presenting the design and making decisions. However, they still need to be fully addressed to the user. In this work, instead of showing ready-made, static images, the view was presented directly from a computer program so that it could be freely changed. In addition, the presence of a designer was ensured so that the user could receive help and explanations when needed. It was crucial that the prototype be understandable to the user and clearly illustrate the new office room. This is extremely difficult when we present unusual solutions for which the user cannot use their previous knowledge, experience, and associations to interpret them. There was a desire to use all the solutions developed in one design. This forced the selection of solutions and their division into several separate variants. The selection of people for testing is arguable. They may be

people who took part in the Discover stage, which was the case in the project, or they may be completely new.

Failure to meet user requirements or the misunderstanding of the prototype results in the need for corrections. It is unknown how many there will be and how long this process will take. Because the design process usually operates within a predetermined time frame, there is little freedom to extend it. Experience, intuition, and good decisions guarantee efficient prototyping and testing. Continuous contact with the user, confirming assumptions, and drawing conclusions is critical to the smooth completion of the entire process. Thanks to this, the testing process for this project took place efficiently and within an acceptable timeframe. However, there is always a risk of incorrect assumptions in the Define phase. When this happens, you must go back into the process and make corrections in the appropriate places. This involves a repetition of actions, this time well-oriented.

Fourth stage—Deliver

Due to the lack of the implementation of this phase of the method in the presented project, documented conclusions cannot be provided. Only recommendations on this issue and areas for review will be given.

The final selection of a given interior design solution and its installation, including lighting, is not the end. Each solution has a specific range of freedom from the installation location and the selection of settings and parameters. These values initially result from the Discover and Define phases. However, the final values are known only later and result directly from a given solution. Only then can a new solution that meets the user's needs be completed and implemented. At this point, implementing the goals of sustainable lighting design and other energy-using systems can be verified. The risk of failing to meet these requirements should be limited because, when using the Design Thinking method, we consider the users' needs for a given space and consider them throughout the design process.

5. Conclusions

To sum up, an approach to designing sustainable solutions that uses standard solutions and models must be revised. People's needs are only partially repeatable. They use the designed devices differently. This project identified the unusual requirements of office employees, which no one talked about or took into account before the planned modernisation. The uniqueness of needs directly results in using devices to ensure comfort, constituting discrepancies between design and use. These, in turn, cause energy consumption to be different than expected.

This article addresses the need for communication between the designer and the user using the Design Thinking method. The designer did not impose solutions on the user, but the results were based on a thorough understanding of his needs. The user was almost always at the centre of the design process. His knowledge allowed designers to look at designing good lighting differently. The user supported the creation of various solutions to meet his needs. The designers' knowledge allowed them to verify these proposals.

Decisions made during design have a crucial impact on future energy consumption, demonstrating the fulfilment of sustainable development goals. The presented project confirmed this. If not for the inclusion of dedicated and user-friendly controls, the lighting would still be left on when employees were absent. If it were not for using appropriate blinds, the lighting would still be turned on on sunny days. This translates into energy consumption and is more than just due to the luminaires and control schedules.

After testing the designed solution, especially after talking to users, there is a guarantee of total acceptance and use of the devices for their intended purpose. It is reasonable that there will be no future problems with their operation, and energy will be consumed as expected in the design. Employee satisfaction, comfort, and efficiency, crucially influenced by lighting, will be high. Therefore, sustainable development will be achieved by meeting people's needs while preserving natural resources.

The presented project successfully used the Design Thinking method, as shown in the literature on other fields.

The problem of discrepancies between the design and use stages presented in the article's introduction can be considered reduced. Users' interference in the operation of devices will be eliminated due to meeting their needs and thus achieving comfortable conditions for them.

The ease of application of Design Thinking in lighting design depends on the case. In the case of lighting modernisation, it is much easier than in the case of new investments; when there are no specific users yet, it is challenging to define them, and we have to use generalisations. The author recommends using the presented method wherever lighting is modernised. There are regular users in such places, and they can take part in the design process. In addition to selecting the desired lighting, the method will indicate other areas related to a given space that should be included in the modernisation process.

Design Thinking and its potential can be used in lighting design and technology. The author sees the possibility of using this method, among other things, for:

- Knowledge about user needs—real, often unrealised, hidden needs, thanks to which we can take them into account when designing lighting and other devices in the field of lighting technology.
- Matching designs—by examining users' needs, a lighting design meets the user's actual needs, which is why it is better used.
- User involvement—we involve users in the design process during needs research and testing. Thanks to this, we can use their knowledge and experience to show our commitment to solving user problems.
- Educational potential—during needs research and testing, we explain to the user how the proposed solution works and why this is and not otherwise. We present what modern technology can offer, thus introducing the user to the basics of lighting, i.e., what is not well known.
- Sustainable resources/environment use—thanks to the knowledge of users' needs, we can choose needed solutions that will be fully used. Thus, we do not introduce options that no one will ever use or luminaires that no one will ever turn on. This allows for better use of resources, thus meeting sustainable development goals.
- Prototyping—having the proposed solutions as a prototype (visualisation, showroom, etc.), we can quickly and inexpensively verify and modify them before implementation.
- Enhance new solutions—new, unusual, non-obvious lighting ideas arise thanks to the inclusion of different people in the design process, often from outside the lighting industry, and getting to know their thoughts and their way of seeing the solution.
- Dealing with the excess of solutions—today, we have many lighting solutions, and thus, it is easy to make the wrong choice. Thanks to the knowledge of the actual needs of the users, choosing the right option is easier and more correct.
- Orientation of science/research—the initiator of the new study is a potential user of their results. The need for research is derived from getting to know user problems and needs.
- The "clash" of lighting standards with users' needs is an actual situation in which the known user requirements will oppose the standards. There is a field for seeking a compromise, and sometimes there may be a need to initiate future changes in the standards.

References

1. Janda, K.B. Buildings don't use energy: People do. *Archit. Sci. Rev.* **2011**, *54*, 15–22. [CrossRef]
2. Ander, G.D. *Daylighting Performance and Design*; John Wiley & Sons: Hoboken, NJ, USA, 2003.
3. Phillips, D. *Daylighting: Natural Light in Architecture*; Elsevier: Burlington, MA, USA; Architectural Press: Princeton, NJ, USA, 2004.
4. Gill, Z.M.; Tierney, M.J.; Pegg, I.M.; Allan, N. Low energy dwellings: The contribution of behaviours to actual performance. *Build. Res. Inf.* **2010**, *38*, 491–508. [CrossRef]
5. *Development Climate Energy*; World Business Council for Sustainable Development (WBCSD): Geneva, Switzerland, 2009.
6. Barlow, S.; Fiala, D. Occupant comfort in UK offices—How adaptive comfort theories might influence future low energy office refurbishment strategies. *Energy Build.* **2007**, *39*, 837–846. [CrossRef]
7. Jazizadeh, F.; Kavulya, G.; Kwak, J.-Y.; Becerik-Gerber, B.; Tambe, M.; Wood, W. Human-Building Interaction for Energy Conservation in Office Buildings. In Proceedings of the Construction Research Congress 2012: Construction Challenges in a Flat World, West Lafayette, IN, USA, 21–23 May 2012; pp. 1830–1839.
8. Hong, T.; Chen, Y.; Belafi, Z.; D'Oca, S. Occupant behavior models: A critical review of implementation and representation approaches in building performance simulation programs. *Build. Simul.* **2018**, *11*, 1–14. [CrossRef]
9. Delzendeh, E.; Wu, S.; Lee, A.; Zhou, Y. The impact of occupants' behaviours on building energy analysis: A research review. *Renew. Sustain. Energy Rev.* **2017**, *80*, 1061–1071. [CrossRef]
10. Chen, S.; Zhang, G.; Xia, X.; Chen, Y.; Setunge, S.; Shi, L. The impacts of occupant behavior on building energy consumption: A review. *Sustain. Energy Technol. Assess.* **2021**, *45*, 101212. [CrossRef]
11. Yang, L.; Liu, S.; Liu, J. The Interaction Effect of Occupant Behavior-Related Factors in Office Buildings Based on the DNAS Theory. *Sustainability* **2021**, *13*, 3227. [CrossRef]
12. Fabi, V.; Andersen, R.V.; Corgnati, S.P.; Olesen, B.W. A methodology for modelling energyrelated human behaviour: Application to window opening behaviour in residential buildings. *Build. Simul.* **2013**, *6*, 415–427. [CrossRef]
13. Pegg, I. Assessing the Role of Post-Occupancy Evaluation in the Design Environment—A Case Study Approach. Ph.D. Thesis, Brunel University, Uxbridge, MA, USA, 2007.
14. Firth, S.; Lomas, K.; Wright, A.; Wall, R. Identifying trends in the use of domestic appliances from household electricity consumption measurements. *Energy Build.* **2008**, *40*, 926–936. [CrossRef]
15. Marcolino, L.S.; Kolev, B.; Price, S.; Veetil, S.P.; Gerber, D.J.; Musil, J.; Tambe, M. Aggregating Opinions to Design Energy-Efficient Buildings. In Proceedings of the 8th Multidisciplinary Workshop on Advances in Preference Handling (M-PREF 2014), Quebec City, QC, Canada, 28 July 2014.
16. Yan, D.; O'Brien, W.; Hong, T.; Feng, X.; Gunay, H.B.; Tahmasebi, F.; Mahdavi, A. Occupant behavior modeling for building performance simulation: Current state and future challenges. *Energy Build.* **2015**, *107*, 264–278. [CrossRef]
17. Heydarian, A.; Pantazis, E.; Wang, A.; Gerber, D.; Becerik-Gerber, B. Towards user centered building design: Identifying end-user lighting preferences via immersive virtual environments. *Autom. Constr.* **2017**, *81*, 56–66. [CrossRef]
18. Attia, S.; De Herde, A.; Gratia, E.; Hensen, J.L.M. Achieving informed decision-making for net zero energy buildings design using building performance simulation tools. *Build. Simul.* **2013**, *6*, 3–21. [CrossRef]
19. Hoes, P.; Hensen, J.L.M.; Loomans, M.G.L.C.; de Vries, B.; Bourgeois, D. User behavior in whole building simulation. *Energy Build.* **2009**, *41*, 295–302. [CrossRef]
20. Maier, T.; Krzaczek, M.; Tejchman, J. Comparison of physical performances of the ventilation systems in low-energy residential houses. *Energy Build* **2009**, *41*, 337–353. [CrossRef]
21. Schakib-Ekbatan, K.; Çakici, F.Z.; Schweiker, M.; Wagner, A. Does the occupant behavior match the energy concept of the building?—Analysis of a German naturally ventilated office building. *Build. Environ.* **2015**, *84*, 142–150. [CrossRef]
22. Martinaitis, V.; Zavadskas, E.K.; Motuziene, V.; Vilutiene, T. Importance of occupancy information when simulating energy demand of energy efficient house: A case study. *Energy Build.* **2015**, *101*, 64–75. [CrossRef]
23. Zero Carbon HUB. *Post-Occupancy Evaluation, Rowner Research Project Phase Two*; Zero Carbon HUB: Milton Keynes, UK, 2015.
24. Yang, J.; Santamouris, M.; Lee, S.E. Review of occupancy sensing systems and occupancy modeling methodologies for the application in institutional buildings. *Energy Build.* **2016**, *121*, 344–349. [CrossRef]
25. Calì, D.; Osterhage, T.; Streblow, R.; Müller, D. Energy performance gap in refurbished German dwellings: Lesson learned from a field test. *Energy Build.* **2016**, *127*, 1146–1158. [CrossRef]
26. D'Oca, S.; Fabi, V.; Corgnati, S.P.; Andersen, R.K. Effect of thermostat and window opening occupant behavior models on energy use in homes. *Build. Simul.* **2014**, *7*, 683–694. [CrossRef]

27. Hong, T.; Yan, D.; D'Oca, S.; Chen, C. Ten questions concerning occupant behavior in buildings: The big picture. *Build. Environ.* **2017**, *114*, 518–530. [CrossRef]

28. Bordass, W. *Flying Blind: Everything You Wanted to Know about Energy in Commercial Buildings but Were Afraid to Ask*; Association for the Conservation of Energy: London, UK, 2001.

29. Leaman, A.; Bordass, B. Are users more tolerant of 'green' buildings? *Build. Res. Inf.* **2007**, *35*, 662–673. [CrossRef]

30. Clevenger, C.M.; Haymaker, J. The Impact of the Building Occupant on Energy Modeling Simulations. In Proceedings of the Joint International Conference on Computing and Decision Making in Civil and Building Engineering, Montreal, QC, Canada, 14–16 June 2006.

31. Kleinsmann, M.; Valkenburg, R.; Buijs, J. Why do(n't) actors in collaborative design understand each other? An empirical study towards a better understanding of collaborative design. *CoDesign* **2007**, *3*, 59–73. [CrossRef]

32. Carrara, G.; Fioravanti, A.; Nanni, U. Knowledge-based Collaborative Architectural Design. *Int. J. Des. Sci. Technol.* **2009**, *16*, 1–16.

33. Belessiotis, V.; Mathioulakis, E. Analytical approach of thermosyphon solar domestic hot water system performance. *Sol. Energy* **2002**, *72*, 307–315. [CrossRef]

34. Lee, B.; Trcka, M.; Hensen, J.L.M. Building energy simulation and optimization: A case study of industrial halls with varying process loads and occupancy patterns. *Build. Simul.* **2014**, *7*, 229–236. [CrossRef]

35. He, Y.; Chen, Y.; Chen, Z.; Deng, Z.; Yuan, Y. Impacts of Occupant Behavior on Building Energy Consumption and Energy Savings Analysis of Upgrading ASHRAE 90.1 Energy Efficiency Standards. *Buildings* **2022**, *12*, 1108. [CrossRef]

36. Owens, S.; Driffill, L. How to change attitudes and behaviour in the context of energy. *Energy Policy* **2008**, *36*, 4412–4418. [CrossRef]

37. Steemers, K.; Yun, G.Y. Household energy consumption: A study of the role of occupants. *Build. Res. Inf.* **2009**, *37*, 625–637. [CrossRef]

38. Darby, S. Energy feedback in buildings: Improving the infrastructure for demand reduction. *Build. Res. Inf.* **2008**, *36*, 499–508. [CrossRef]

39. Hensen, J.; Lamberts, R. *Building Performance Simulation for Design and Operation*; Taylor & Francis: Abingdon, UK, 2011; pp. 56–84.

40. Veitch, J.A.; Hine, D.W.; Gifford, R. End users' knowledge, beliefs, and preferences for Lighting. *J. Inter. Des.* **1993**, *19*, 15–26. [CrossRef]

41. Zhang, W.; Tan, S.; Lei, Y.; Wang, S. Life cycle assessment of a single-family residential building in Canada: A case study. *Build. Simul.* **2014**, *7*, 429–438. [CrossRef]

42. Zahedi, M.; Guité, M.; De Paoli, G. Addressing user-centeredness: Communicating meaningfully through design. In Proceedings of the 14th International Conference on Computer Aided Architectural Design Futures, Liege, Belgium, 4–8 July 2011; pp. 513–524.

43. Li, Z.; Jiang, Y.; Wei, Q.T. Survey on Energy Consumption of Air Conditioning in Summer in a Residential Building in Beijing. *J. Heat. Vent. Air Cond.* **2014**, *37*, 46–51.

44. Santin, O.G.; Itard, L.; Visscher, H. The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock. *Energy Build.* **2009**, *41*, 1223–1232. [CrossRef]

45. Ren, Z.; Yang, F.; Bouchlaghem, N.M.; Anumba, C.J. Multi-disciplinary collaborative building design—A comparative study between multi-agent systems and multi-disciplinary optimisation approaches. *Autom. Constr.* **2011**, *20*, 537–549. [CrossRef]

46. Feringa, J. Notes on the Potential of Simulation for Architectural Conception. In Proceedings of the 28th Annual Conference of the Association for Computer Aided Design in Architecture, Minneapolis, MN, USA, 16–19 October 2008; pp. 264–269.

47. Gunay, H.B.; O'Brien, W.; Beausoleil-Morrison, I. A Critical review of state-of-the-art energy and comfort related occupant behavior in office buildings. *Build. Environ.* **2013**, *70*, 31–47. [CrossRef]

48. Zahedi, M.; Guité, M.; de Paoli, G. Dealing with the human-centered approach within HCI projects. In Proceedings of the Design Research Society International Conference, 2010: Design & Complexity, Montreal, QC, Canada, 7–9 July 2010.

49. Dong, B.; Lam, K.P. A real-time model predictive control for building heating and cooling systems based on the occupancy behavior pattern detection and local weather forecasting. *Build. Simul.* **2014**, *7*, 89–106. [CrossRef]

50. Kim, M.J.; Cho, M.E.; Jun, H.J. Developing Design Solutions for Smart Homes Through User-Centered Scenarios. *Front. Psychol.* **2020**, *11*, 516355. [CrossRef] [PubMed]

51. Bogenstätter, U. Prediction and optimization of life-cycle costs in early design. *Build. Res. Inf.* **2000**, *28*, 376–386. [CrossRef]

52. Cross, N. Forty years of design research. *Des. Stud.* **2007**, *28*, 1–4. [CrossRef]

53. Boyarski, D.; Buchanan, R. Brief—Carnegie Mellon University. *Interactions* **2000**, *7*, 20–23. [CrossRef]

54. Zahedi, M.; Poldma, T.; Baha, S.E.; Haats, T. Design Thinking and Aesthetic Meaning-Making: Interlaced Means to Engage in Collaborative Knowledge-Building. In Proceedings of the NordDesign 2012, 9th Conference on Engineering Design and Product Development, Aalburg, Denmark, 22–24 August 2012; pp. 627–637.

55. Dugar, A.M. Slow Design. A new standard for connected Lighting? *Light. India* **2019**, *14*, 11–12.

56. Reinhart, C.F.; Voss, K. Monitoring manual control of electric lighting and blinds. *Light. Res. Technol.* **2003**, *35*, 243–258. [CrossRef]

57. Nicol, J.F.; Humphreys, M.A. Adaptive thermal comfort and sustainable thermal standards for buildings. *Energy Build.* **2002**, *34*, 563–572. [CrossRef]

58. Klein, L.; Kwak, J.-y.; Kavulya, G.; Jazizadeh, F.; Becerik-Gerber, B.; Varakantham, P.; Tambe, M. Coordinating occupant behavior for building energy and comfort management using multi-agent systems. *Autom. Constr.* **2012**, *22*, 525–536. [CrossRef]

59. Bullinger, H.-J.; Bauer, W.; Wenzel, G.; Blach, R. Towards user centred design (UCD) in architecture based on immersive virtual environments. *Comput. Ind.* **2010**, *61*, 372–379. [CrossRef]

60. Romm, J.J. *Lean and Clean Management: How to Boost Profits and Productivity by Reducing Pollution*; Kodansha USA Inc.: New York, NY, USA, 1994.
61. Liedtka, J. Why Design Thinking Works. *Harv. Bus. Rev.* **2018**, *9–10*, 72–79.
62. Brown, T. *Change by Design: How Design Thinking Transforms Organizations and Inspires Innovation*; Harper Business: New York, NY, USA, 2019.
63. Brown, T. Design Thinking. *Harv. Bus. Rev.* **2008**, *6*, 72–79.
64. Dam, R.F.; Siang, T.Y. What is Design Thinking and Why Is It So Popular? Interaction Design Foundation. Available online: https://www.interaction-design.org/literature/article/what-is-design-thinking-and-why-is-it-so-popular (accessed on 10 November 2023).
65. Chasanidou, D.; Gasparini, A.A.; Lee, E. Design Thinking Methods and Tools for Innovation. In *Design, User Experience, and Usability: Design Discourse: 4th International Conference, DUXU 2015, Held as Part of HCI International 2015, Los Angeles, CA, USA, August 2–7, 2015, Proceedings, Part I*; Springer: Cham, Swizterland, 2015; pp. 12–23.
66. Słupik, S.; Kos-Łabędowicz, J.; Trzęsiok, J. Are You a Typical Energy Consumer? Socioeconomic Characteristics of Behavioural Segmentation Representatives of 8 European Countries. *Energies* **2021**, *14*, 6109. [CrossRef]
67. Zissis, G. Energy Consumption and Environmental and Economic Impact of Lighting: The Current Situation. In *Handbook of Advanced Lighting Technology*; Karlicek, R., Sun, C.C., Zissis, G., Ma, R., Eds.; Springer: Cham, Switzerland, 2016; pp. 1–13.
68. Nelson, H.G.; Stolterman, E. *The Design Way*, 2nd ed.; The MIT Press: Cambridge, MA, USA, 2014.
69. Cooper, R.; Junginger, S.; Lockwood, T. Design thinking and design management: A research and practice perspective. *Des. Manag. Rev.* **2009**, *20*, 46–55. [CrossRef]
70. Plattner, H.; Meinel, C.; Leifer, L. *Design Thinking*; Springer: Berlin, Germany, 2011.
71. Brenner, W.; Uebernickel, F.; Abrell, T. Design thinking as mindset, process, and toolbox. In *Design Thinking for Innovation*; Brenner, W., Uebernickel, F., Eds.; Springer: Cham, Switzerland, 2016; pp. 3–24.
72. Micheli, P.; Wilner, S.J.S.; Bhatti, S.H.; Mura, M.; Beverland, M.B. Doing design thinking: Conceptual review, synthesis, and research agenda. *J. Prod. Innov. Manag.* **2019**, *36*, 124–148. [CrossRef]
73. Constain Moreno, G.E.; Collazos, C.A.; Blasco, S.B.; Moreira, F. Software Design for Users with Autism Using Human-Centered Design and Design Thinking Techniques. *Sustainability* **2023**, *15*, 16587. [CrossRef]
74. Magistretti, S.; Bianchi, M.; Calabretta, G.; Candi, M.; Dell'Era, C.; Stigliani, I.; Verganti, R. Framing the multifaceted nature of design thinking in addressing different innovation purposes. *Long Range Plan.* **2022**, *55*, 102163. [CrossRef]
75. Niehaus, M.; Mocan, M. Cultivating Design Thinking for Sustainable Business Transformation in a VUCA World: Insights from a German Case Study. *Sustainability* **2024**, *16*, 2447. [CrossRef]
76. Lockwood, T. *Design Thinking: Integrating Innovation, Customer Experience, and Brand Value*; Allworth Press: New York, NY, USA, 2009.
77. Stickdorn, M.; Schneider, J. *This Is Service Design Thinking*; BIS Publishers: Amsterdam, The Netherlands, 2014.
78. Design Methods for Developing Services. An Introduction to Service Design and a Selection of Service Design Tools. Available online: https://www.designcouncil.org.uk/fileadmin/uploads/dc/Documents/DesignCouncil_Design%2520methods%2520for%2520developing%2520services.pdf (accessed on 10 November 2023).
79. *EN 12464-1:2021*; Light and Lighting—Lighting of Work Places—Part 1: Indoor Work Places. Slovenian Institute for Standardization: Ljubljana, Slovenia, 2021.
80. *EN 1838:2013*; Lighting Applications—Emergency Lighting for Buildings. Slovenian Institute for Standardization: Ljubljana, Slovenia, 2013.
81. *EN 15193-1+A1:2021-09*; Energy Performance of Buildings—Energy Requirements for Lighting—Part 1: Specifications, Module M9. Slovenian Institute for Standardization: Ljubljana, Slovenia, 2021.
82. Flager, F.; Gerber, D.J.; Kallman, B. Measuring the impact of scale and coupling on solution quality for building design problems. *Des. Stud.* **2014**, *35*, 180–199. [CrossRef]
83. O'Brien, W.; Gunay, H.B. The contextual factors contributing to occupants' adaptive comfort behaviors in offices—A review and proposed modeling framework. *Build. Environ.* **2014**, *77*, 77–87. [CrossRef]
84. Cole, R.J.; Brown, Z. Reconciling human and automated intelligence in the provision of occupant comfort. *Intell. Build. Int.* **2009**, *1*, 39–55. [CrossRef]
85. *ANSI/ASHRAE Standard 55*; Thermal Environmental Conditions for Human Occupancy. ASHRAE: Peachtree Corners, Georgia, 2010.
86. Tuniki, H.P.; Jurelioni, A.; Fokaides, P. A review on the approaches in analysing energy-related occupant behaviour research. *J. Build. Eng.* **2021**, *40*, 102630. [CrossRef]
87. Lashinaa, T.; Chraibia, S.; Despenica, M.; Shrubsoleb, P.; Rosemanna, A.; van Loenena, E. Sharing lighting control in an open office: Doing one's best to avoid conflict. *Build. Environ.* **2019**, *148*, 1–10. [CrossRef]
88. Martins, F.; Almeida, M.F.; Calili, R.; Oliveira, A. Design Thinking Applied to Smart Home Projects: A User-Centric and Sustainable Perspective. *Sustainability* **2020**, *12*, 10031. [CrossRef]
89. Haldi, F. A probabilistic model to predict building occupants' diversity towards their interactions with the building envelope. In Proceedings of the BS2013: 13th Conference of International Building Performance Simulation, Chambery, France, 26–29 August 2013.

90. Steg, L. Promoting household energy conservation. *Energy Policy* **2008**, *36*, 4449–4453. [CrossRef]
91. Design Kit: The Human-Centered Design Toolkit. Available online: https://www.ideo.com/post/design-kit (accessed on 10 November 2023).
92. Stanford d.school. *Bootcamp Bootleg*; Hasso Plattner Institute of Design: Stanford, Palo Alto, CA, USA, 2011.
93. Durak, A.; Olguntürk, N.; Yener, C.; Köksal, D.; Gürçınar, Y. Impact of lighting arrangements and illuminances on different impressions of a room. *Build. Environ.* **2007**, *42*, 3476–3482. [CrossRef]
94. Kleinsmann, M.; Valkenburg, R. Barriers and enablers for creating shared understanding in co-design projects. *Des. Stud.* **2008**, *29*, 369–386. [CrossRef]
95. Preece, J.; Rogers, Y.; Sharp, H. *Interaction Design: Beyond Human-Computer Interaction*, 3rd ed.; Wiley: New York, NY, USA, 2011.
96. Bridges, A.; Charitos, D. On architectural design in virtual environments. *Des. Stud.* **1997**, *18*, 143–154. [CrossRef]
97. Zhang, L.; Goßmann, J.; Stevenson, C.; Chi, M.; Cauwenberghs, G.; Gramann, K.; Schulze, J.; Otto, P.; Jung, T.; Peterson, R.; et al. Spatial cognition and architectural design in 4D immersive virtual reality: Testing cognition with a novel audiovisual CAVE-CAD tool. In Proceedings of the Spatial Cognition for Architectural Design Conference, New York, NY, USA, 16–19 November 2011.
98. How Virtual Environments Could Help Architects? Available online: https://www.arch2o.com/virtual-augmented-reality-could-help-architects/ (accessed on 10 November 2023).
99. Krupiński, R. Virtual Reality System and Scientific Visualisation for Smart Designing and Evaluating of Lighting. *Energies* **2020**, *13*, 5518. [CrossRef]
100. Mahmoudzadeh, P.; Afacan, Y.; Adi, M.N. Analyzing occupants' control over lighting systems in office settings using immersive virtual environments. *Build. Environ.* **2021**, *196*, 107823. [CrossRef]