The Impact of Dynamic Lighting in Classrooms. A Review on Methods

Ellen Kathrine Hansen(✉), Stine Maria Louring Nielsen, Diana Georgieva, and Kathrine Marie Schledermann

Lighting Design, Department of Architecture, Design and Media Technology, Aalborg University, A.C. Meyers Vænge 15, 2450 Copenhagen, SV, Denmark
{ekh, stm, kat}@create.aau.dk,
diana.z.georgieva@gmail.com

Abstract. In order to understand how research can support lighting designs to improve nurturing environments for learning, a literature review was carried out. The review examined lighting research methods and parameters used for evaluating the effect of dynamic lighting in classrooms. The test parameter gaining most attention in the studies is academic performance; whereas qualitative test parameters, such as behaviour and mood, are addressed in less than a third of the selected studies. The analysis of these methods leads to a conclusion that learning environments to a broader extent should be studied and designed holistically through a mixed method approach. It is suggested that the potentials of dynamic lighting in learning environments are explored through design driven innovation and the use of mixed methods, in order to be able to put more emphasis on the students' and teachers' needs for dynamic lighting scenarios.

Keywords: Design research · Learning environment · Lighting in classrooms
Mixed methods · User-centric lighting design · Design driven innovation
Dynamic lighting

1 Introduction

Lighting technology has undergone a revolution, revealing new potentials of integrating lighting as a central parameter for improving the learning environment and nurturing the passion for learning in schools. Potentials of meeting new needs for differentiated learning situations and human needs for dynamic lighting are in focus, but not yet validated and specified as design parameters in the design of dynamic lighting. In order to approach a design perspective which can support learning environments more holistically, it is relevant to investigate *how the effects of dynamic lighting in classrooms can be evaluated* and to discuss *how this knowledge can be integrated in the process of designing dynamic lighting for classrooms.*

This review provides an overview and a critical perspective on research and methods used to measure the effects of dynamic classroom lighting. To address the real-life effects of lighting, this review focuses on field studies in classrooms, gathered from the library of Aalborg University, ProQuest search engine, ResearchGate, and Google Scholar.

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In this paper, the *learning environment* is defined as the combination of the physical environment (the classrooms); the learning activities which take place in this environment during school hours, and the behaviour of the students which affects or might affect these activities.

The term *dynamic lighting* refers to intelligent, automatic systems with one or more parameters changing over time - such as light intensity, correlated colour temperature (CCT), or distribution. It also includes lighting, which consists of scenes with predefined light parameters. The term *daylight* is used for light of natural origin, including sunlight and skylight, while incandescent, fluorescent, LED, HPSV, and others, are referred to as *artificial* or *electrical* lighting.

The definition of a *mixed methods* approach refers to Creswell [1]: the use of both qualitative and quantitative methods in a study; the data from both of which are analysed; and are merged, connected, or embedded. This is as opposed to a quasi-mixed approach, which includes both methodologies without them being integrated.

2 Reviews

2.1 Academic Performance as Test Parameter

One of the most common ways to measure the effects of light on students is to test their progression in test scores or concentration over time. Many researchers choose to do so by analysing the scores from specifically chosen or prepared *standardised tests*, rather than exploring the school grades. Over forty years ago, this method was employed by Mayron et al. [2] in investigating the effects of cool white and full-spectrum fluorescent light on the reading performance of first-grade children. Their results were inconclusive as it was not possible to isolate the variables and an assumption was made that the observed difference in the performance of students was due to differences in teaching.

Through the use of standardised tests, the influence of two predefined light settings on reading performance - accuracy, speed, and expression - were tested by Mott et al. [3]. The analysis showed that the reading improved more under the *focus* setting (6000 K, 1000 lx) in comparison to the *normal* (3500 K, 500 lx), during the study. Another experiment on dynamic light tested the effects of three settings, with different CCT and intensity levels, on student performance through field and laboratory experiments [4]. First, a preliminary study investigated effects of light on arousal as a potential mediator of performance. It showed that warmer colour temperature (3500 K) had a relaxing effect on the seventeen adult subjects. Afterwards, a laboratory experiment was conducted which, in contrast, showed no change in the performance of students when solving an arithmetical problem. However, the field study that took place afterwards confirmed the results from the pre-test, revealing a possible strong influence on performance for the setting with the highest CCT (6500 K). A similar contradiction between a field and a controlled experiment was present in a study on dynamic light by Sleegers et al. [5]. Mott et al. [3] also reported that their field study showed no effect of lighting on motivation, in contrast to a laboratory experiment

conducted by Knez [6]. This could indicate that field experiments, which test in conditions much closer to everyday life, could be more precise in predicting the effect of lighting on the learning potentials of students in real-life situations.

The method of comparing the school grades of children was also utilised in a study on the effects of increased horizontal and ambient illumination on multiple factors, including academic achievement [7]. The experimental classrooms were equipped with fluorescent luminaires emitting direct and indirect light, plus extra fixtures to increase the light levels on the walls. The findings showed an interesting discovery in that, while there was a small difference between the progression in achievement for the experiment and control groups over the time of the study, a pronounced effect was evident during the dark season.

Between 2012 and 2014, four field studies have examined the effects of light on *concentration*. All of them used the d2 Test of Attention and experimented with LED, fluorescent lights, or both. Barkmann et al. [8] conducted an experiment where seven fluorescent lighting settings were presented to the teachers and it was up to them to decide when, how, and how often to use them. The results showed that under the *Concentrate* lighting scenario (5800 K, 1060 lx) the students made fewer errors of omission compared to the *Standard* setting (4000 K, 300 lx). The effect of dynamic LED light, as opposed to fluorescent light, was investigated by Sleegers et al. [5] in one laboratory and two field experiments. The light differed in CCT and intensity and was controlled by the teacher, similarly to Barkmann's experiment. The results of the field studies showed that the children performed better on the d2 test in the experimental *Focus* setting (6500 K, 1000 lx) compared to the *Standard* (3000–4000 K, 300 lx). However, the controlled study showed no effect. The findings of another field study on dynamic lighting from the same year showed no improvement in the students' concentration under 6000 K, 1000 lx compared to 3500 K, 500 lx [3].

Regarding the effects of light on student performance, there are still questions that remain unanswered. There is an indication that field experiments, which test in conditions much closer to everyday life, could be more precise in predicting the effect of lighting on the learning potentials of students in real-life situations. This indicates a need for developing methods for holistic field research, in contrast to merely using quantitative methods and studying quantitative parameters, such as test scores and grades. Hereto, Keis et al. [9] point out that the long-term exposure to blue-enriched light in the morning needs to be further investigated. Choi and Suk [4] suggest that future research should address how light affects students of different ages, and Sleegers et al. [5] point out that future studies could examine the effects of light on children with cognitive and behavioural learning disabilities. In addition, there is a lack of studies comparing the effects of fluorescent, LED light, and other light sources.

2.2 Behavior and Mood as Test Parameters

In this section, field research on the impact of dynamic light on behaviour, mood, and use of light in classrooms is presented. The inattentive and the off-task *behaviours* of students were observed under full-spectrum fluorescent light with shielded electromagnetic radiation by Wohlfarth [10]. This was measured by documenting the direction in which the students were looking and various other behaviours, using structured

observations. The results of the study were contradictory as some of the behaviours increased in occurrence while others decreased under the experimental lighting. Another study which investigated concentration as a dependent variable was conducted by Kuller and Lindsten [11]. First they assessed the classroom behaviour of students through a scale consisting of 18 items, including concentration, and they later compared it to the levels of cortisol (a stress hormone which is affected by light). What they reported was a possible negative relationship between the cortisol levels and concentration. However, no further research has examined this in relation to classroom environments. In 2016, another investigation was conducted using a qualitative approach. The effects of colour temperature (3000 K and 4100 K, fluorescent light) on students' on-task behaviour was explored by Pulay et al., by documenting their physical location during class, using structured observations [12]. The analysis showed an increase in their concentration under the cooler light setting. Another field study by Keis et al., investigated the effects of blue-enriched LED light on the cognitive performance (processing speed, concentration, and memory) of high-school students in morning classes [9]. The control group was under warm fluorescent lighting (3000 K, 3500 K), while the experimental group was under blue-enriched LED light (5500 K). They found a positive impact of the experimental light on the concentration of the participants.

Wessolowski et al. tested the effects of the Philips SchoolVision system, which is based on fluorescent lighting, and compared its *Relax* setting (3500 K, 325 lx) to its *Standard* setting (4000 K, 300 lx) in order to evaluate the effects on fidgetiness, aggressive, and pro-social behaviour [13]. The impact was explored through detecting the pixel changes in a digital recording through structured observations and by self-rating assessments. Under *Relax*, a decline in restlessness and aggressive behaviour was observed. A tendency towards an increased pro-social behaviour was also reported.

The effects of light on *mood* were studied in a static-group comparison by Wohlfarth [10], where the students were exposed to either (1) a combination of interior colours, (2) full-spectrum light, (3) colours and light, or control lighting. A significant correlation was found between *light and colours* and *mood*, which was examined through a mood variation test. In the schools with the *light* and *colour/light* conditions, the students had a greater feeling of Surgency and Mastery/Self-Esteem. However, the children in the control and in the *colour/light* school both scored higher on Aggression in comparison to the other two. Another study by Raynham et al. examined the impact of indirect light on the mood of students on the ground and first floors of a school, measured through a self-rating scale [7]. The results showed a difference between the experimental and control classrooms on the ground floor, revealing a steady improvement of the mood after December under the indirect light setting as opposed to a heavy decline followed by a slight improvement in the control.

The analysis of the selected field research on the impact of dynamic light on behaviour and mood indicates that concentration is increased under cooler blue-enriched light, whereas exposure to warmer light reduces restlessness and aggressive behaviour and affects positively pro-social behaviour. This indicates that there is a need for flexible learning environments meeting various needs through different lighting scenarios. The methods used for studying the effects of light on *behaviour and mood* are qualitative, whereas the data are typically quantified. These data

would be valuable for setting up and testing design criteria, as well as for performing correlational analysis. The use of advanced technologies for generating quantitative data on behaviour (as in Wessolowski et al. [13]) could also mean that researchers would be able to work with large sample sizes of students and achieve results that are more generalizable. However, it should be considered that providing designers with qualitative data on the most human aspect of the classroom environment - the human behaviour and mood - could lead them to developing a more empathetic relation with the people they design for, and could add "meaning and individuality to the statistics" [14, p. 114]. Thus, this review identifies a need to rethink the methodologies applied when investigating and measuring the potentials and effects of innovative technologies (such as lighting) that can spark and nurture passions for learning in the real-life learning environments of children.

3 Result

The selected studies, which include academic performance as a test parameter, made up more than 75% of the reviewed literature (half of which studies solely the effects on performance). In comparison, around one third investigates the effects of light on behaviour, mood, and/or use of light (Fig. 1, Left). Half of the studies applied exclusively quantitative methods, while only less than 10% applied qualitative ones; 22% used mixed methods, and 18% - quasi-mixed (Fig. 1, Right).

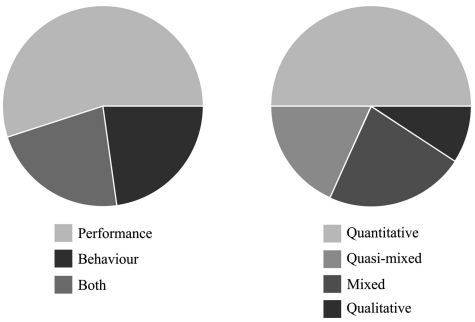

Fig. 1. Methods and parameters included in selected studies

The effects of light on *academic performance* are almost exclusively studied quantitatively - fifteen out of the seventeen reviewed studies. This approach allows the acquisition of data for very large, comparable sample sizes of students (Table 1).

However, Mott et al. [3] suggest that other ways of measuring student performance, such as behavioural observations (applied in: [10, 12]) might show better results. Analysing the concentration of students through documenting their spatial location in the classroom [12], despite the quantification of data, provides an image and allows the designer to get a glimpse of what is happening in the real-life environment. While Wohlfarth [10] did not obtain conclusive findings after measuring on-task behaviour

Table 1. List of included studies on the learning environment and investigated effects.

Author(s)	Year	Investigated the effects of light on	Methods used	Tools
Mayron, Ott, Nations, Mayron	1974	Performance Hyperactive behaviour Sick days	Mixed	Academic tests Performance objectives Observation timelapse
Ne'eman et al.	1976	Preference for sunlight Use of light	Mixed	Interviews Questionnaires
Wohlfarth	1986	Mental development Performance Attitudes toward school Misbehaviours Absences due to illness Refractive eye problems Blood pressure Dental caries Off-task behaviours Sound intensity levels	Quasi-mixed	Structured observations Achievement tests The School Subjects Attitude Scales (SSAS) Discip. actions taken Sound level Measurements Pre-adolescent Mood Variation tests (PAMS) Blood pressure
Hathaway	1992	Dental caries Attendance rates Rates of achievement Health and general dev.	Quan	Test of Basic Skills
Kuller, Lindsten	1992	Body growth Sick leave Cortisol levels Ability to concentrate Sociability	Mixed	Structured observations Cortisol
Heschong Mahone Group	1999	Academic performance Mood	Quasi-mixed	Iowa Test of Basic Skills (ITBS) Grades from schools Interviews
Yarbrough	2001	Student achievement	Quan	Iowa Test, Basic Skills
Axarli, Meresi	2008	Use of light Visual comfort	Mixed	

(*continued*)

Table 1. (*continued*)

Author(s)	Year	Investigated the effects of light on	Methods used	Tools
Tanner	2009	Student achievement	Quasi-mixed	Iowa Test, Basic Skills
Raynham, Govén, Laike	2011	Mood Sleepiness Quality of sleep Academic performance Sick-leave Cortisol, Melatonin	Quan	Scores School Tests Self-rating scale
Barkmann, Wessolowski, Schulte-Markwort	2012	Attention Reading speed Reading comprehension Achievement Motivation Classroom atmosphere	Quan	d2 Test of Attention ELFE 1–6 LGVT 6–12 Questionnaire for Emotional and Social Exp. (FEESS)
Mott, Robinson, Walden, Burnette, Rutherford	2012	Concentration Motivation Oral reading fluency	Quan	d2 Test of Attention AIMSweb An instrument adapted from Pintrich (1990)
Sleegers et al.	2013	Concentration	Quan	d2 Test of Attention
Keis, Helbig, Streb, Hille	2014	Concentration Cognitive processing Memory retention Attitude to the lighting	Quan	d2 Test of Attention Test (ZVT) Visual and Verbal Memory Test
Wessolowski, Koenig, Schulte-Markwort, Barkmann	2014	Fidgetiness Prosocial behaviour Aggressive behaviour	Quasi-mixed	Change of pixels CRS; Conners, (1973) Observation System Aggressiveness Self-assessment tools
Buckley	2014	Use of light Visual comfort	Qual	Interviews Observations
Barrett, Zhang, Davies, Barrett	2015	Academic performance	Quan	Progression in test scores from the schools
Choi and Suk	2016	Arousal Accuracy, Speed Sense time passed	Quan	Electrocardiogram Solving arithmetical pr.

(*continued*)

Table 1. (*continued*)

Author(s)	Year	Investigated the effects of light on	Methods used	Tools
Ahadi et al.	2016	Performance Feeling of drowsiness	Mixed	Academic scores Daylight quality
Drosou et al.	2016	Use of the light	Quan	Documenting HDRI
Pulay et al.	2016	On-task behaviours	Qual	Mapping stud. location

through qualitative methods, the contradictory results raise questions such as what the right way is to measure the effects of light on performance and whether qualitative methods could help explain the results in more detail.

Behaviour has an impact on classroom activities, academic performance of students [15], and the use of physical space, including light, making it one of the most influential factors. Additionally, interpersonal and hyperactive behaviour also have an impact on the well-being and mood of teachers, who in turn affect the students and the classroom environment [16]. This means that exploring and mastering the relationship between behaviour and light can lead to opportunities for creating lighting designs with great impact on classroom environments. Nevertheless, it should be considered that through observing behaviour it is not possible to understand what the students are learning and how much. Thus, despite its importance, behaviour cannot be the only factor used for measuring the effects of light on students and learning.

Research indicates that warm CCT and low light intensity are conducive to reducing aggression and restlessness, boosting pro-social behaviour and feeling of relaxation, and supporting students with special educational needs [4, 13, 17], which might actually be the opposite of what is good for performance [4, 5, 8, 9, 18]. However, other research shows a positive correlation between pro-social classroom behaviour and academic performance [19]. This shows how little we still know about the effects of light on different aspects, and indicates to the authors that a more holistic and user-centric approach is necessary.

When people are involved, it is crucial to consider that only they can reveal what really generates value for them. An example of this can be found in a study by Keis et al. [9] who found a positive effect of blue-enriched light on the concentration of students. Despite this effect, questionnaires regarding the satisfaction with light showed that the students preferred the appearance of the standard lighting, and only 50% wanted to keep the new one.

Good communication between users and designers can potentially lead to innovative design solutions [20]. Qualitative data can be used as a tool for improving the conversation between users, researchers, and designers, by providing different tools for communication, such as images, videos, and stories [21]. Having these tools is important when users, researchers and designers of different ages, backgrounds, and roles in the study and design process, need to communicate experiences, knowledge, and ideas (an issue increasingly addressed in healthcare research and design: [22–24]).

The UK Design Council report emphasizes the need for involving the students and school staff in the design process, stating that the "genuine involvement of users empowers individuals, produces greater satisfaction [with the renovated spaces] and should improve the design" [25, p. 7]. According to another British report "the learning environment should 'belong' to the community, involving teachers, students and community members in the design process" [26, p. 17]. Mixing qualitative and quantitative methods might be the most suitable approach for analysing the complex experiences and needs of the users, the relations between the various human and environmental factors, as well as the long-standing issues of energy efficiency and optimization of resources (addressed in: [27, 28]). In recent years, qualitative and quantitative methods are increasingly being mixed in order to address these complex issues [14, 29]. According to Wisdom and Creswell, a mixed methods study "reflects participants' point of view" and gives "a voice to study participants, and ensures that study findings are grounded in participants' experiences" [30, p. 3]. When applying mixed methods in investigating multiple factors, combining knowledge and practices from different fields is essential. Such a transdisciplinary approach is valuable for understanding how light can become a multidimensional design element, meeting criteria validated through methodologies from different scientific fields [31].

4 Conclusion

This literature review examined lighting research methods used for evaluating the effects of dynamic light in classrooms. The overall aim for this study was to understand how research can support innovative lighting designs for meeting the needs of users, and thus supporting environments for learning.

The reviewed literature uncovers potentials of dynamic lighting for improving the learning environment. Especially the effects of changing CCT and light intensity during the dark seasons, long-term exposure to blue-enriched light in the morning to increase concentration, and warm light to reduce aggression and promote a prosocial behaviour have potentials that need to be investigated.

The test parameter gaining most attention in the reviewed field studies is academic performance, which is investigated in the majority of the studies and mostly through quantitative methods. Behaviour and mood are addressed in one third of the selected papers and predominantly studied through qualitative methods, analysed through a quantification of collected data. Additionally, field tests could be more precise in predicting the effect of lighting on the learning environment, which points out needs for developing methods for holistic field research.

This review leads to a recommendation that more test parameters and the relations between them should be studied through a holistic approach. This could include elements of the physical environment - light, air, temperature, noise, colours - as well as human parameters, such as behaviour, performance, health, mental well-being, and perception.

It is suggested that the relation between dynamic light and these test parameters is explored through the use of mixed methods to draw from the strengths and minimize the weaknesses of qualitative and quantitative methods - and to be able to put more

emphasis on the users' perspective. Studying multiple variables through different methods requires the collaboration of specialists from various disciplines of technology, design, and social sciences, such as lighting design, architecture, pedagogy, and anthropology, in a transdisciplinary approach.

References

1. Creswell, J.W.: Research Design: Qualitative, Quantitative, and Mixed Methods Approaches, 4th edn. SAGE Publications Inc., USA (2014)
2. Mayron, L.W., Ott, J., Nations, R., Mayron, E.L.: Light, radiation, and academic behavior. Acad. Ther. **X**(1), 33–47 (1974)
3. Mott, M.S., Robinson, D.H., Walden, A., Burnette, J., Rutherford, A.S.: Illuminating the effects of dynamic lighting on student learning. SAGE Open **2012**, 1–9 (2012)
4. Choi, K., Suk, H.J.: Dynamic lighting system for the learning environment: performance of elementary students. Opt. Soc. Am. (OSA), **24**(10) (2016)
5. Sleegers, P.J.C., Moolenaar, N.M., Galetzka, M., Pruyn, A., Sarroukh, B.E., van der Zande, B.: Lighting affects students' concentration positively: findings from three dutch studies. Lighting Res. Technol. **45**, 159–175 (2013)
6. Knez, I.: Effects of indoor lighting on mood and cognition. J. Environ. Psychol. **15**, 39–51 (1995)
7. Raynham, P.J., Govén, T., Laike, T.: Influence of ambient light on the performance, mood, endocrine systems and other factors of School children. In: Proceedings of the 27th Session of the CIE Sun City, South Africa (2011)
8. Barkmann, C., Wessolowski, N., Schulte-Markwort, M.: Applicability and efficacy of variable light in Schools. Physiol. Behav. **105**, 621–627 (2012)
9. Keis, O., Helbig, H., Streb, J., Hille, K.: Influence of blue-enriched classroom lighting on students' cognitive performance. Trends Neurosci. Educ. **3**, 8–92 (2014)
10. Wohlfarth, H.: Colour and Light Effects on Students' Achievement, Behavior and Physiology. Alberta Department of Education, Edmonton (1986)
11. Kuller, R., Lindsten, C.: Health and behavior of children in classrooms with and without windows. J. Environ. Psychol. **12**, 305–317 (1992)
12. Pulay, A., Read, M., Tural, E., Lee, S.: Examining student behavior under two correlated color temperature levels of lighting in an elementary school classroom. Educ. Plann. **23**(3), 57–69 (2016)
13. Wessolowski, N., Koenig, H., Schulte-Markwort, M., Barkmann, C.: The effect of variable light on the fidgetiness and social behavior of pupils in school. J. Environ. Psychol. **39**, 101–108 (2014)
14. Kington, A., Sammons, P., Day, C., Regan, E.: Stories and statistics: describing a mixed methods study of effective classroom practice. J. Mixed Methods Res. **5**(2), 103–125 (2014)
15. Straus C., Tiffany D.M.: Strategies to Improve Low-Performing Schools Under the Every Student Act (2016). https://www.americanprogress.org/issues/education/reports
16. Nierenberg, C.: Depression in Teachers Impacts Classroom Learning (2015). http://www.livescience.com/49771-depression-teachers-impacts-classroom-learning.html
17. BRANZ Ltd.: Designing Quality Learning Spaces: Lighting. New Zealand: Ministry of Education (2007). ISBN 0-478-13619-6; WEB ISBN 0-478-13624-2
18. Hathaway, W.E.: A Study Into the Effects of Types of Light on Children - A Case of Daylight Robbery. IRC Internal Report, Canada (1992)

19. Wentzel, K.R.: Does being good make the grade? social behavior and academic competence in middle School. J. Educ. Psychol. **85**(2), 357–364 (1993)
20. Sidawi, B.: The impact of social interaction and communications on innovation in the architectural design studio. Buildings **2012**(2), 203–217 (2012)
21. Fraser, H.M.A.: Design Works: How to Tackle Your Toughest Innovation Challenges Through Business Design. University of Toronto Press, Toronto (2012)
22. Hamilton, D.K.: Collaborators must work together to share results. Res. Des. J. **9**(1), 107–109 (2015). Health Environments
23. Kasali, A.: Architects in interdisciplinary contexts: representational practices in healthcare design. Des. Stud. **41**, 205–223 (2015)
24. Lehoux, P., Hivon, M.: The worlds and modalities of engagement of design participants: a qualitative case study of three medical innovations. Des. Stud. **32**, 313–332 (2011)
25. Higgins, S., Hall, E., Wall, K., Woolner, P., McCaughey, C.: The Impact of School Environments: A Literature Review. UK Design Council report (2005)
26. Building Futures: 21st Century Schools. Learning Environments of the Future. Building Futures, UK (2004)
27. Drosou, N., Brembilla, E., Mardaljevic, J., Haines, V.: Reality bites: measuring actual daylighting performance in classrooms. In: Proceedings of PLEA 16, Los Angeles, 11–13 July 2016 (2016)
28. Plympton, P., Conway, S., Epstein, K.: Daylighting in Schools: improving student performance and health at a price schools can afford. Paper presented at American Solar Energy Society Conference, NREL/CP-550-28049 (2000)
29. Strudsholm, T., Meadows, L.M., Vollman, A.R., Thurston, W.E., Henderson, R.: Using mixed methods to facilitate complex, multiphased health research. Int. J. Qual. Methods **15** (1), 1–11 (2016)
30. Wisdom, J., Creswell, J.W.: Mixed Methods: Integrating Quantitative And Qualitative Data Collection And Analysis While Studying Patient-Centered Medical Home Models. Agency for Healthcare Research and Quality, Rockville, MD, AHRQ Publication No. 13-0028-EF, p. 3 (2013)
31. Hansen, E.K., Mullins, M.: Lighting design: toward a synthesis of science, media technology and architecture. eCAADe, **2**(1), 613–620 (2014)