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Integrating Human Satisfaction into the Design Phase – Generating Motivation and Knowledge in Architectural Education

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1 ABSTRACT

The design of sustainable cities and buildings needs to include thoughts on circumstances influencing human satisfaction be it for thermal, visual, or other dimensions of human perception. While human satisfaction should be regarded as a dimension of sustainability alone, the provision of thermal and visual satisfaction is also a key driving force for energy use in buildings. Research on human perception of the built environment and their interactions with it has a long tradition. At the same time, open research questions especially with respect to the interaction between different dimensions of human perception, e.g. the effect of thermal stimuli on visual perception, are part of the current debate within the research community. In contrast, the amount of scientific knowledge related to human satisfaction transferred to architectural students is low and consequences of their decisions during design studio works for the later occupants are seldom addressed.

This paper describes the experiences and results of a teaching experiment, in which architectural students were asked to reflect their own design work finished in a previous year with respect to effects on human satisfaction by means of experimental studies. The research questions raised were a) which design issues can be investigated through experimental studies, and b) to what extent can the motivation of architectural students towards the topic of occupants' satisfaction be raised. A seminar consisting of three phases was conducted in two consecutive summers. First, students received input related to scientific methods, thermal and visual perception, and had to reflect on one of their previous design works in order to extract research questions and hypotheses. In the second phase, students had to design and conduct a small experimental study related to their research questions. In addition, they had to participate in the experiments organized by their fellow students. In the third phase, the experimental data was analysed and had to be presented together with the reflection of consequences for future design works.

The results of this teaching experiment show the huge variety of design issues dealt with in the context of this seminar. Research questions originating from the students were in parts related to cutting edge research questions such as the interaction between different dimensions of perception. From the perspective of a raised motivation, a large number of students showed great interest in the topic, participated with enthusiasm, and evaluated this seminar very high. Limitations have to be seen in the small sample sizes reachable by this seminar approach with many experiments being conducted with less than 10 participants due to limited resources in time and budget, and in the low level of statistical knowledge, which is not part of architectural education.

Keywords: experimental study, education, design work, occupant behaviour, occupant satisfaction

2 INTRODUCTION

The design of sustainable cities and buildings needs to include thoughts on circumstances influencing human satisfaction be it for thermal, visual, or other dimensions of human perception. While human satisfaction should be regarded as a dimension of sustainability alone, the provision of thermal and visual satisfaction is also a key driving force for energy use in buildings (Holmes and Hacker, 2007). The variety of human interactions with buildings caused by thermal or visual dissatisfaction can lead to variations in the energy use of magnitude 3 and above (Andersen, 2012).

The provision of thermal comfort has gained importance in the context of passive cooling concepts. Between the 1970's and 2004, the expected level of thermal comfort was assessed independent of the type of room conditioning based on standards, which neither consider the outdoor environmental conditions nor individual opportunities for adaptation (ISO 7730, 2005; ASHRAE, 1992). These standards and related predictive models of thermal comfort were based on subjective studies in laboratory environments. Based on a large number of in-situ studies asking occupants at their workspace instead, the adaptive comfort model was developed and implemented into standards (ASHRAE, 2004; EN 15251, 2012). The adaptive comfort model adjusts the temperature considered as comfortable according to the outdoor conditions due to postulated behavioural, physiological, and psychological adaptive mechanisms (de Dear, Brager and Cooper, 1997). As such, there is a much larger potential for passive cooling concepts to perform within given standards. Still, only a limited number of influencing factors is considered in these models, all of them physically measurable. In contrast, Frank (1975) already mentioned numerous other influences on thermal comfort, partly affected by design decisions such as the office type, partly by other aspects of the physical indoor environment such as visual and acoustic aspects.

The relevance of light for well-beeing and satisfaction of users did become evident with the scientific proof of non-visual effects of light on humans in 2001 (Brainard et al., 2001). Shading systems and artificial lighting meeting only the (minimum) requirements of building standards, and controls of shading and lighting regarding only energy efficiency are perceived as annoying by the users. Therefore, in recent years many field studies and laboratory studies have been conducted that show the importance of a view to the outside, of illuminance levels above the minimum requirements and the influence of time of day and season on users‘ satisfaction (Collins, 1975; Begemann, van den Beld and Tenner, 1997; Galasiu and Veitch, 2006; Moosmann, 2015).

Most of these findings from research related to additional influencing factors on thermal and visual comfort are not available in predictive models for engineering tasks. However, an increased awareness among current and future architects especially of design aspects and their effect on peoples' satisfaction and well-being could enhance the number of sustainable designs for cities and buildings. At the same time, open research questions especially with respect to the interaction between different dimensions of human perception, e.g. the effect of thermal stimuli on visual perception, are part of the current debate within the research community (Chinazzo, Wienold and Andersen, 2018). In contrast, the amount of scientific knowledge related to human satisfaction transferred to architectural students is low and consequences of their decisions during design studio works for the later occupants are seldom addressed.

This paper describes experiences and results of a teaching experiment, in which architectural students were asked to reflect their own design work finished in a previous year with respect to effects on human satisfaction. The topic of this seminar connects to long-standing research activities of KIT's Building Science Group (Moosmann, Schweiker and Kalz, 2015; Wagner and Schakib-Ekbatan, 2011; Kleber and Wagner, 2006; Schweiker, Hawighorst and Wagner, 2016; Schweiker and Wagner, 2017; Wagner et al., 2015).

From the professional perspective, the overall objective of this teaching experiment was to increase the students' awareness of the effect of their design decisions on latter occupants' satisfaction. From the methodological perspective, students should acquire knowledge regarding experimental approaches in research, their potential, and limitations. In addition, the lecturers and researchers could experiment with new formats and topics for experiments on human satisfaction and extend their research portfolio. As such, this teaching experiment is in line with Humboldt's' definition of research at universities, which describes universities as places where student and teacher are both there for science by jointly considering science as an undissolved problem, which will keep them researching (Humboldt, 1808).

The research questions raised were a) which design issues can be investigated through experimental studies, and b) to what extent can the motivation of architectural students towards the topic of occupants' satisfaction be raised.

3 METHOD

3.1 Teaching experiment

In order to answer these questions, the seminar consisting of three phases was conducted twice in two consecutive summer semesters. The seminar consisted in general of weekly meetings of 90 minutes each, except for the experimental phase (see below), which covered two full days in each semester.

In the first phase, students received input related to newest findings related to thermal and visual perception, and had to reflect on one of their previous design works in order to extract research questions and hypotheses. In the second phase, students had to design and conduct a small experimental study related to their research questions. In addition, they had to participate in the experiments organized by their fellow students. Like this, they experienced both the role of an experimenter/researcher and of a study participant/future occupant. In the third phase, the experimental data was analysed and had to be presented together with the reflection of consequences for future design works. Table 1 presents the three phases of the seminar together with the corresponding input by lecturers and students.

Phase	Input by lecturers	Input by students	Joint work
1 Hypothesis finding	Extended foundations of thermal and visual comfort Introduction to research methods in general with focus on experimental work	Reflection of previous design works with respect to design decisions affecting thermal and/or visual comfort Formulation of research questions and hypothesis	Reflection and sharpening of research questions and hypotheses
2 Research design and implementation	Introduction to experimental design and the available facility and its equipment	Development of research design, (if required) materials, questionnaires, guidelines, checklists	Implementation of research design Participation in experimental studies
3 Analysis and presentation	Introduction into analysis methods and graphical representation of a large number of data points	Analysis of data Preparation of presentation	Reflection and discussion on results and their consequences.

Table 1: Seminar phases of teaching experiment

Due to the intensive supervision effort and the limited temporal availability of the research facility (described below), only 5 to 10 students could be accepted each summer. In the first year, five students participated in this teaching experiment, which resulted in 4 ECTS for the students. In the second year, eight students participated. In the first phase, the students were first asked to generate two research questions related to thermal and visual perception each based on a previous design work, i.e. four research questions by each student. In three meetings, first within the complete group of participants, later only with parts of the group, these 20 (first year) / 36 (second year) research questions were dicussed and combined to 4 to 6 research questions in total. This lower number of research questions made it feasible to be implemented into research designs conducted within 2 to 3 working days, so that the total amount of time spent for experiments did not cover a too large fraction of the 120 working hours assigned to this seminar. As a result, 2 to 3 students each were responsible for one or two experiments; in exceptional cases, a single student was responsible for a single experiment. Such restrictions also limited the number of subjects for each experiment as discussed below.

The limited number of students in each year was the reason for repeating the seminar twice with hardly any changes (see below) in order to have a sufficient sample to evaluate this teaching experiment. Besides the continuous self-evaluation by the lecturers, Human Resources Development and Vocational Training (PEBA) of KIT conducted a structured interview after each years' final presentation. The questions for this interview were developed in cooperation between PEBA, the lecturers and other persons involved in this teaching experiment. The interview took place in the same room as the final presentation and lasted for 30 to 45 minutes. The lecturers were not present during these interviews and students were assured anonymity in their responses. One member of PEBA, who was also present during the interview, presented the results of the interview to the lecturers around 4 weeks after the interview in a separate meeting ensuring the anonymity of responses. In the second year, a questionnaire based standard evaluation was conducted during the third phase of the seminar.

3.2 Experiments conducted by students

All experimental studies were conducted in an experimental facility used by the authors' (and lecturers) for real scientific projects and equipped with numerous sensors and a high degree of flexibility – the Laboratory for Occupant Behaviour, Satisfaction, Thermal comfort and Environmental Research (LOBSTER) (Schweiker et al., 2014; Building Science Group, 2015; Wagner et al., 2018). This test facility consists of two full size office rooms (4 * 6 * 3 m^3 - w * l * h). In contrast to typical climate chambers used in the field of thermal comfort, one of the four walls of the LOBSTER is a post-and-beam structure with around 60%

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glazing and two operable windows to the outdoors. If granted by the research design, participants can tilt or open these windows, adjust the external Venetian blinds, adjust the electrical lighting and/or the thermostat for heating and cooling. All actions together with physiological responses (heart rate, skin temperature, skin conductance level) and psychological responses (via questionnaires) can be logged electronically.

As mentioned above, participants of each experiment were the participants in this seminar not involved in the design of the experiment. In order to keep the purpose of each experiment hidden, consultations were done individually between lecturers and students and not in the group. In addition, all students were asked to motivate additional students, family members or friends in order to increase the sample size. No incentives other than cakes or other food was given to the participants.

Depending on the research question, students had to build elements of their design work in the scale 1:1 in order to attach it to the LOBSTER. For example, one group built an external vertical shading device made out of black cloths, while another group build a 2m by 4m honeycomb grid and placed it above the windows in order to simulate a pergola access made of galvanized steel grilles (see Fig. 1).

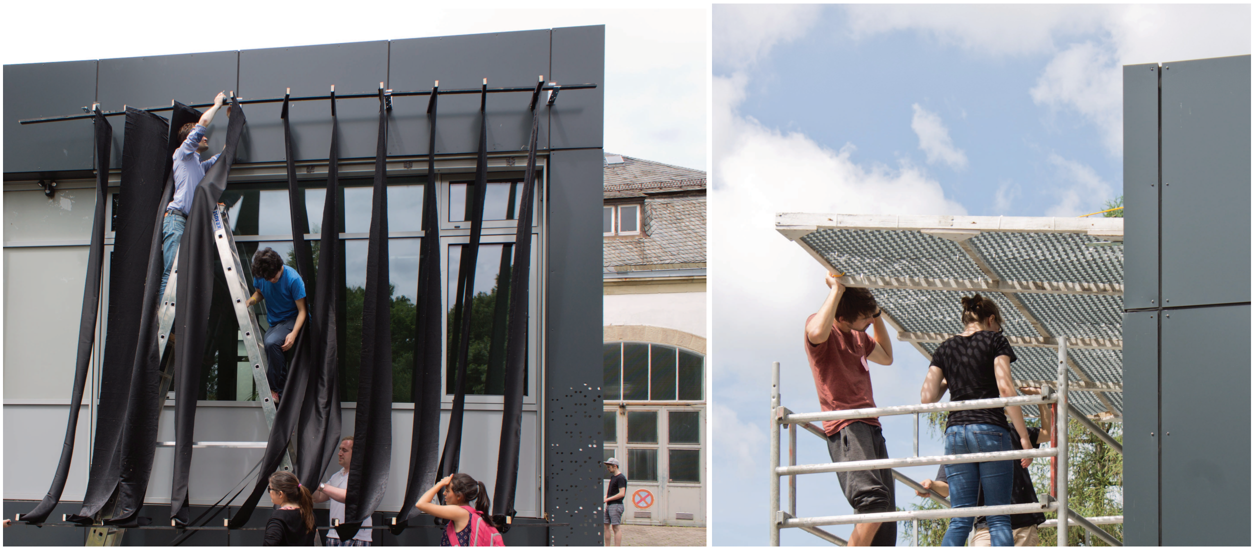

Fig. 1: Students (and lecturer) installing 1:1 elements of their students design works for the experiments (left: black cloths simulating a vertical shading device, right: honeycomb grid simulating a pergola access made of galvanized steel grilles)

4 RESULTS OF STUDENT EXPERIMENTS

The research designs conducted within this teaching experiment show a huge variety of design issues dealt with in the context of this seminar and can be grouped into the following three main topics: (1) interactions between different dimensions of comfort, (2) effects on optimal conditions for the operation of buildings and (3) shading devices from an architectural viewpoint. Thereby, the research questions originating from the students were in parts related to cutting edge research questions in the scientific community such as the interaction between different dimensions of perception.

4.1 Interactions between visual, thermal, and acoustic perception

The interaction between different dimensions of human perception is a topical subject in research. Related research questions, were also a recurring topic raised by the students. Thereby, the independent variables, those hypothesized to have an effect, as well as the dependent variable varied strongly between the groups. Table 2 summarizes the key features of the students' design works, and the related research questions of selected works.

An experimental design was developed and implemented for each of these three research questions. In all cases, a within-subject design, i.e. each participant experienced all available conditions, was chosen due to the expected small sample size and variety of secondary influences due to differences in participants individual preferences and personality. Due to the limitation of paper length, only the experiment NoiseCon will be described here with more detail.

Project ID	Key feature of design work	Research question (s)
NoiseCon	Work place or dance studio behind translucent façade	Is there an interaction between the view outside (IV1) and noise (IV2) on the general satisfaction (DV1) and power of concentration (DV2)? – Is noise more disturbing when its source is visible?
NoiseSat	Residential building close to a heavily trafficked street	To what extent is satisfaction with thermal indoor environment (DV1) and the window opening behaviour (DV2) affected by the noise from the street (IV)?
Market	Market place with high window-to-wall ratio	Is the decision to buy food (DV) influenced by the visual (IV1) and thermal conditions (IV2)?

Table 2: Key features of students' design works and related research question (DV: dependent variable, IV: independent variable).

There were four subjects participating in NoiseCon, who each experienced two conditions – clear and translucent view to the outside (see Fig. 2). The order of conditions was balanced to avoid the influence of learning effects on the performance, i.e. two participants started with the clear view and the other two participants with the translucent view. Noise was generated at a pre-set schedule through one of the experimenters driving around the test facility with his moped the same way during both conditions. Each condition lasted for 60 minutes during which participants had to fill out questionnaires and perform two concentration tasks used in previous research projects, namely addition of two-digit numbers and the n-back task (Wacker, Chavanon and Stemmler, 2006).

Fig. 2: Experimental set-up of NoiseCon (left: clear view, right: translucent view realized by multiple layers of translucent foil bought at a nearby homecenter for less than 5 €).

Fig. 3 shows the results of the experiment with respect to the general satisfaction and ability of concentration. General satisfaction differed between both offices when assessed five minutes after entering the office. However, such difference disappeared at the end of each condition, i.e. 60 minutes later. The view to the outside did not affect the ability of concentration, participants showed the same performance with a clear and a translucent view. Statistical test did not show any significant differences.

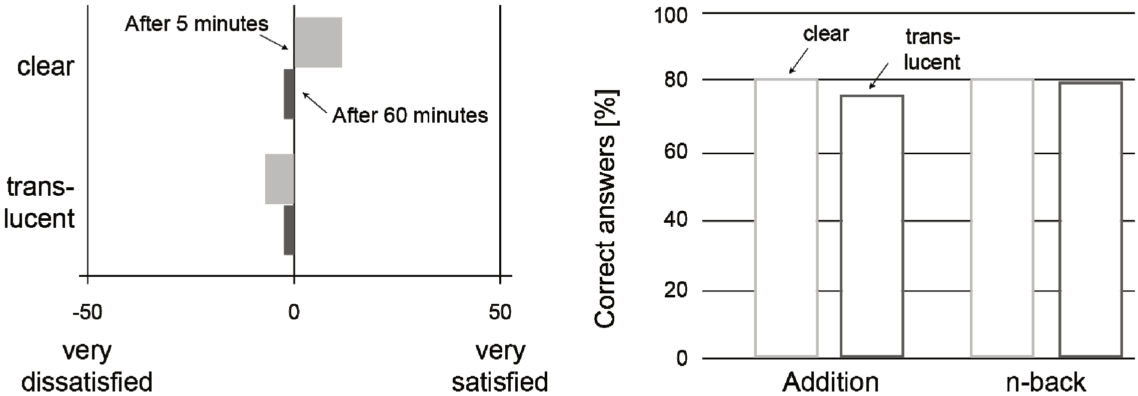

Fig. 3: General satisfaction and power of concentration in experiment NoiseCon. Figures reproduced from student works with permission by Serge Cormont, Isaak Svoboda and Franziska Fritz.

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The project NoiceSat (N = 8 participants) revealed significant differences in the interaction between noise and temperature: satisfaction with thermal conditions and window opening behaviour differed between the condition with and without outside noise (generated through sound boxes outside the LOBSTER playing pre-recorded traffic noise). The project Market showed no effect of thermal conditions (one room was conditioned at 20°C, the other at 32°C) on the visual effects of different light sources.

4.2 Shading devices from architectural and perceptual view

A recurring topic in both years was the architectural and perceptual view on shading devices such as alternatives to Venetian blinds and overhangs. The necessity to add shading devices increases with a high window-to-wall ratio favoured by many architects. However, shading devices in the form of Venetian blinds themselves appear to "destroy" the architectural appearance of the design. Therefore, alternatives are added to the design work without knowing much about their effects on human perception. Table 3 summarizes the key features of two student design works and the related research questions.

Project ID	Key feature of design work	Research question (s)
HoriVert	Vertical fixed external blinds made of cloths	Is there a difference in the perception (DV) between horizontal and vertical blinds (IV)?
Pergola	Pergola access made of galvanized steel grill in multi-family residential building	Is the visual satisfaction and reading performance inside a living room (DV) affected by a galvanized steel grill or closed element situated above the window (IV)?

Table 3: Key features of students' design works and related research question (DV: dependent variable, IV: independent variable).

Both projects required 1:1 "models" of the object of interest as shown above in Fig. 1. Project HoriVent had four participants experiencing two different conditions: a room with a horizontal and another with a vertical shading device. The students assessed visual satisfaction and the performance in an addition task. Both measures showed slight but non-significant advantages for the vertical shading device (see Fig. 4, left).

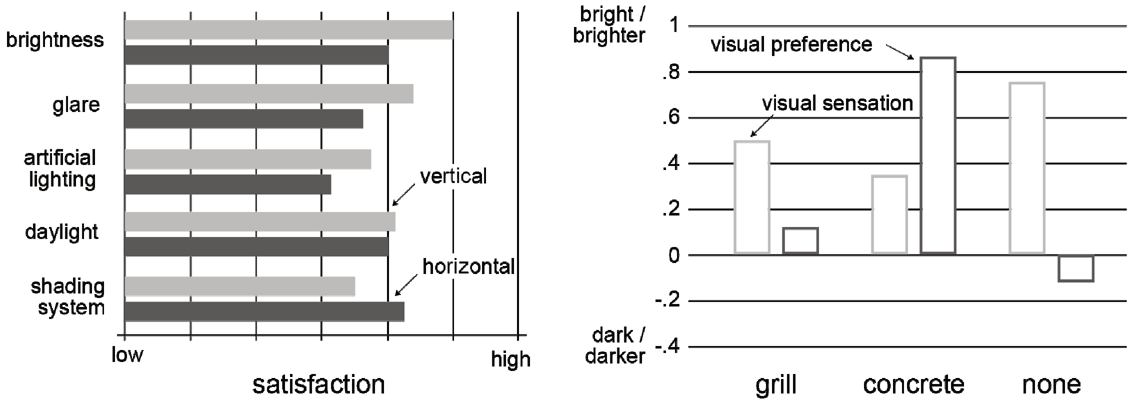

Fig. 4: Results from projects HoriVent (left) and Pergola (right). Figures reproduced from student works with permissions by Gloria Wendeler and Alejandra Gutiérrez Murillo (HoriVent) and Constanze Havard-Beltz and Oscar Chiu da Margerie (Pergola).

The experiment Pergola had three conditions: no overhang, overhang as grill, closed overhang. Participants (N = 8) were asked to sit far away from the window and to read a text provided by the student experimenters for 10 minutes. This was followed by a questionnaire assessing visual sensation and preferences. Fig. 4 (right) shows that the perception followed the pre-defined hypothesis, that visual perception was brightest for the condition without overhang, followed by the grill and the visual preference showed the invers trend.

4.3 Optimal conditions for the operation of buildings

The intended focus of this seminar was on questions related to design decisions as part of architectural practice and their consequences on human perception and behaviour. However, the reflections of the students and following discussions led to research questions focussing on the operation of buildings. Table 4 summarizes the key features of the students' design works, and related research questions of selected experiments/projects.

Project ID	Key feature of design work	Research question (s)
Market	Market place	Is the decision to buy food (DV) influenced by the type of light source (IV)?
MovieTemp	Movie theatre	Does the optimal temperature for movie theatres (DV) vary with the type of movie (IV) shown?

Table 4: Key features of students' design works and related research question (DV: dependent variable, IV: independent variable).

In the first project, Market, participants (N = 9) were asked to evaluate how likely they would buy a red fruit presented with four different types of artificial light sources and natural light alone (Fig. 5, left). The light sources (halogen lamp, LED and compact fluorescent lamp) were chosen to modify the redness of the fruits. As shown in Figure 5 (right), the highest probability of buying was related to halogen lamp and warm white LED lamp. Additional questions were asked, among others, for the perceived tastiness, visual appeal, or naturalness. Answers showed similar trends as shown in Figure 5.

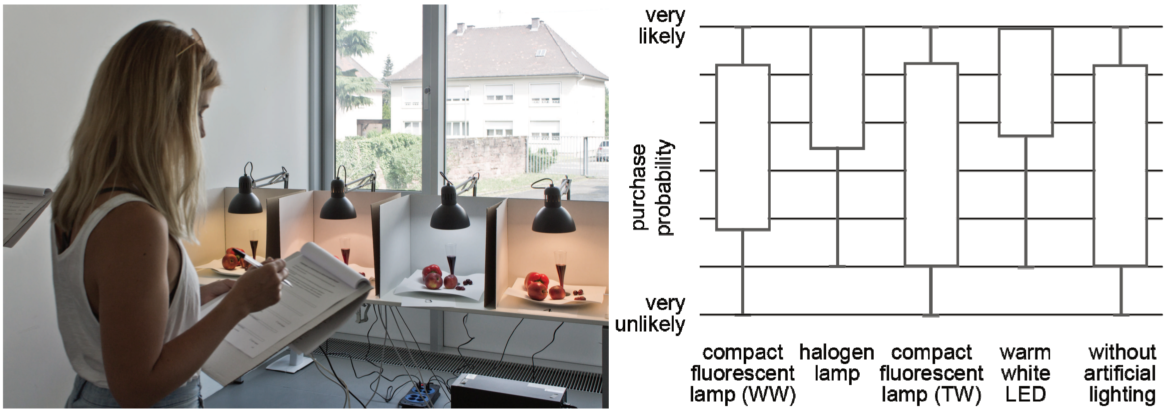

Fig. 5: Experimental setting of project Market (left) and likelihood of buying one of the items presented (right). Right figure reproduced from student work with permissions by Elena Schmitt and Ann-Kathrin Holmer.

The research question of the project MovieTemp is related to latest research findings looking at the effect of emotions on thermal perception (Huebner and Shipworth, 2017), still a hardly researched topic. While the room was darkened and indoor temperature kept the same, participants (N = 10) viewed either a rather boring documentation or a sequence of an action movie for 15 minutes each in a balanced order. In addition to questionnaires assessing the thermal perception, skin temperature was measured at 4 points according to ISO 9886 (2004) in order to assess physiological differences. This experiment was affected by several unexpected events, such as garment falling down during the experiments and changing the visual conditions or wrong temperature set points in one of the two rooms. None of these was the fault of the student, but had as consequence, that the data of this experiment could not be analysed feasibly– another learning effect that besides extensive preparations things can go wrong in scientific experiments as well.

5 DISCUSSION, LIMITATIONS AND CONCLUSIONS OF TEACHING EXPERIMENT

An important learning objective of this teaching experiment was the skill to generate research questions based on a design work. Background is the aim to have students reflecting their design decisions and consequences beyond functional and aesthetical aspects in future design works. This phase lasted for 4 weeks and consisted of several discussions between students and lecturers and between students and students in order to sharpen the initial thoughts towards suitable research questions. Students were given the task to write down four research questions and present them in the second week of the seminar. As expected, these first questions were seldom focused on the viewpoint of human perception and mainly not suitable to be transferred into experimental designs. Exemplarily the development for the project NoiseSat shall be described. The initial question was "Is ventilation through the North façade meaningful given that the design work had a double façade to the South, where the heavily trafficked street was?" This initial question was analysed with respect to human perception: does it make a difference for the residents whether ventilation is provided from North or South? Additional consultations and analyses revealed a question much more interesting from the architectural, design point of view: Is a double façade necessary or rather, is the influence of noise entering the living rooms much more likely without the double façade on residents' satisfaction?

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Limitations in the choice of research questions arose due to time constraints, the determination of experimental studies in a given facility, and the limited number of potential participants. Time constraints appeared, where questions could be answered solely through experiments lasting for several hours. The given facility, the LOBSTER, is designed for research on offices and room dimensions and, even more important, openings were fixed and could not be changed (e.g. to test the effect of a large top light with people walking above it on the ability of concentration of those working in the room). Still the predefined usage was not a large issue as shown by experiments looking at sportive activities, sales markets, classroom scenarios, or movie theatres.

Gaining hands-on experiences with a nearly complete research design process, from research question and hypothesis generation, development and conduction of an experimental design, data collection and analysis, up to the presentation of the results, was an important pedagogical objective of this teaching experiment. Internal reflection of the teaching experiments showed, that the focus on this nearly complete research process, lead to the exclusion of any kind of literature review – an important step in "real" science. Besides the professional input by the lecturers given before students developed their research question, students did not have the full knowledge regarding the state of the art in each sub-area of the field. Therefore, some of the research questions could have been answered through a literature review alone without having to conduct an experiment. Such research questions have not been stopped by the lecturers, because a) other limitations were already high, b) the objective of this teaching experiment was not to allow solely experiments never done before, and c) something done by oneself has a much higher potential to be remembered than something read. For future applications of this teaching experiment, it might be worth testing whether the professional input after the students' initial research questions, focussing on these questions directly would lead to other, more innovative experiments.

One aspect adjusted already between the first and second year, was the treatment of input with respect to data analysis and presentation. The final presentations in the first year revealed that the architectural students were overwhelmed by the amount of data and had difficulties to present them in a way understandable for listeners not involved in the experiments. Internal reflection clarified that the content of an architectural degree course with the focus on design works, drawing, and physical models does not include topics related to data handling, analysis, and their presentation. In addition, scientific writing and presentation is also an issue. In order to strengthen this part of the teaching experiment, a workshop element was added in the second year. Two experts in data visualization from the House of Competence (HoC) at KIT and the National Institute for science communication (NaWiK) prepared and conducted this workshop. The focus was on methods to define the core statements based on the given results and to visualize data. The effect is exemplarily shown in Fig. 6, with two original figures by students from the first and second year. The figure from the second year is much easier to be understood even without additional verbal explanation and much more clear in conveying its core statement. Whether this was a result of the additional workshop or of different initial skills of the student groups cannot be proven by such small sample size without control group. Still, the lecturers considered this as a successful, fruitful and important element of this teaching experiment.

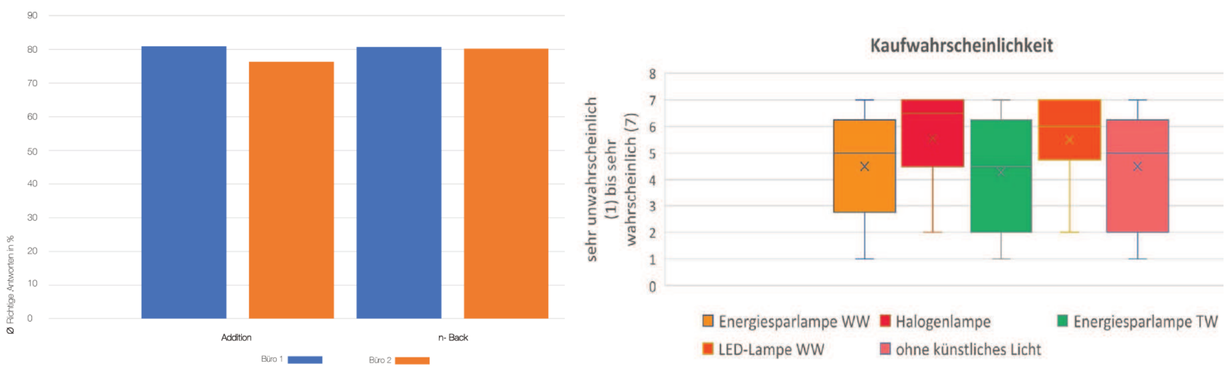

Fig. 6: Comparison of original students drawing from first year (left, same content as Fig. 3, right) and second year (right, same content as Fig. 4, right) presentation (original drawings by students).

Further limitations have to be seen in above mentioned small sample sizes. Even though some results revealed significant differences between the conditions, the projects described above are good examples to show the potentials, but also difficulties of such experiments conducted within a weekly seminar. The observed effects are often too small to be detected by such small sample sizes, especially due to large inter-individual differences. Consequently, students had difficulties to formulate conclusions and design decisions based on their data, because they were missing a clear trend. At the same time, even the small sample sizes lead to the observation by the students, that human perception differs between individuals and that others do not necessarily share their (architectural) view. It should be highlighted here, that such observation was one of the pre-defined professional educational objectives of this teaching experiment.

Time limitations of course also affect the generalizability of the results, which was not an objective of this teaching experiment. For example, the two research questions related to shading devices presented above cannot be fully answered through an experiment on a single summer day. For a sound evaluation of the (dis-)advantages of a proposed shading device it is necessary to consider a variety of sky conditions (clear, cloudy), solar elevations (morning, noon, afternoon), and external illuminance levels (summer, winter). Still, the experiments raised the awareness among the students involved, which aspects are relevant and which (dis-)advantage their system might have. One of the students wrote in the final essay, that “there would not have been enough daylight in the kitchen I designed, because the room depth of my design was even higher than in the LOBSTER”.

With respect to the question, whether interest on questions related to human perception can be raised by such teaching experiment, the interviews and evaluation by PEBA were of great help for such reflection. The answers given during the interviews showed that especially the second year was very successful in motivating students both for human perception as well as for research work per se. In the interviews conducted by PEBA, students praised the seminar especially for its high practical relevance for their future work. This is supported by the standard evaluation by questionnaires, which led to a value of the “teaching quality index” of 100, which is the highest obtainable value. In addition, the lecturers observed that nearly all students showed great interest in the topic and participated with enthusiasm in the seminar including their own experiments and those of their fellow students. In summary, an external qualitative evaluation of a new seminar is highly recommended in order to reveal strengths and weaknesses of the chosen approach.

In conclusion, the experiments conducted by students showed that a large variety of design aspects can be transferred into research questions assessed through experimental studies. Limitations have to be seen in parts in the small sample sizes reachable by this seminar approach with many experiments being conducted with less than 10 participants due to limited resources in time and budget and the low level of statistical knowledge, which is not part of architectural education. The small sample size does not permit a scientific after-usage of the results by the lecturers; however, this was never the intention. From the viewpoint of the two lecturers involved, who both actively research in the area of human satisfaction, the seminar was successful and a promising element towards a wider spread of design works incorporating thoughts on human satisfaction.

6 ACKNOWLEDGEMENTS

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