Can we measure buildings' affordance?

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ABSTRACT

The term affordance is used in this paper to denote the capacity of buildings to provide occupants the possibility to control the indoor-environmental conditions so as to meet their needs and requirements. This is typically facilitated via buildings' various control devices and systems meant to control ambient conditions. In this paper, we discuss recent progress in developing a building affordance evaluation method. The idea is to evaluate buildings' control devices and elements based on their availability as well as their effectiveness. We critically examine the strengths and weaknesses of the proposed affordance measurement method and discuss its future potential to be used as a performance assessment tool by professionals and stakeholders in building design and operation.

INTRODUCTION

The term affordance has been used differently, depending on the context (Gibson 1977, 1979). It is thus important to clarify the use of this term in the present contribution, which is more akin to the ecological valency concept in human ecology (Knötig 1992a, 1992b; Mahdavi 2016, 2019). With buildings' affordance, we mean the aptitude of buildings to provide occupants the possibility to adjust ambient conditions so as to meet their expectations. Thereby, we specifically focus on the controllability of indoor-environmental (thermal, visual, auditory, olfactory) conditions.

Affordance may be provided via both passive and active systems and devices. The former category includes, for instance, manually operated windows and blinds for natural ventilation and solar control. The latter category includes mechanical systems for heating, cooling, ventilation, and illumination. Typically, occupants can interact with such systems via dedicated user interfaces. Interfaces may be a simple mechanical element (e.g., a window grip) or of digital nature (e.g., a control interface on a mobile phone). The importance of the presence and functionality of indoor-environmental control systems and their user interfaces is widely recognized. Somewhat surprisingly, however, they have not been the subject of formal building performance assessment methods and schemes. To be clear, there are of course a multitude of codes, standards, and guidelines that are concerned with buildings' energy, ecological, and indoor-environmental performance. But there have been, to our knowledge, few efforts to formally assess or rate buildings' indoor-environmental control interfaces with regard to the extent they accommodate occupants' need to modify various aspects of the ambient conditions.

In this paper, we report on such an effort. This effort involved the introduction of a building affordance assessment method together with an associated protocol. Thereby, the objective was to systematically document and evaluate the availability and effectiveness of indoor-environmental control systems and their user interfaces. The assessment protocol includes five effectiveness categories, namely *i)* spatial distribution, *ii)* objective performance, *iii)* subjective performance, *iv)* interface quality, and *v)* ecological performance. The protocol included procedures to allocate credits depending on the availability and functionality of the interfaces as well as methods to aggregate such credits over the buildings' different systems and different spaces so as to arrive at both room-level and building-levels indicators of affordance.

AN AFFORDANCE EVALUATION PROTOCOL

The proposed protocol for affordance assessment builds upon earlier work in this area (Mahdavi et al. 2019). The focus of the entailed procedures in this protocol is not to assess buildings' indoor-environmental (specifically, thermal, visual, auditory, olfactory) conditions at any specific point in time. Rather, the intention is to assess the principal availability and effectiveness of indoor-environmental control elements, devices, and systems.

The proposed method incorporates a point (or credit) assignment strategy. This aids the derivation of a so-called "affordance index" (AI). AIs can be obtained for individual zones or rooms within the building and subsequently aggregated in terms of whole-building overall AI value. Thus, buildings could be benchmarked and compared. Toward this end, the proposed affordance evaluation protocol is designed to consider the means and opportunities buildings offer for controlling indoor environmental conditions. Such means include, for example, windows, shading elements, luminaires, and equipment for space heating and cooling (see Figure 1).

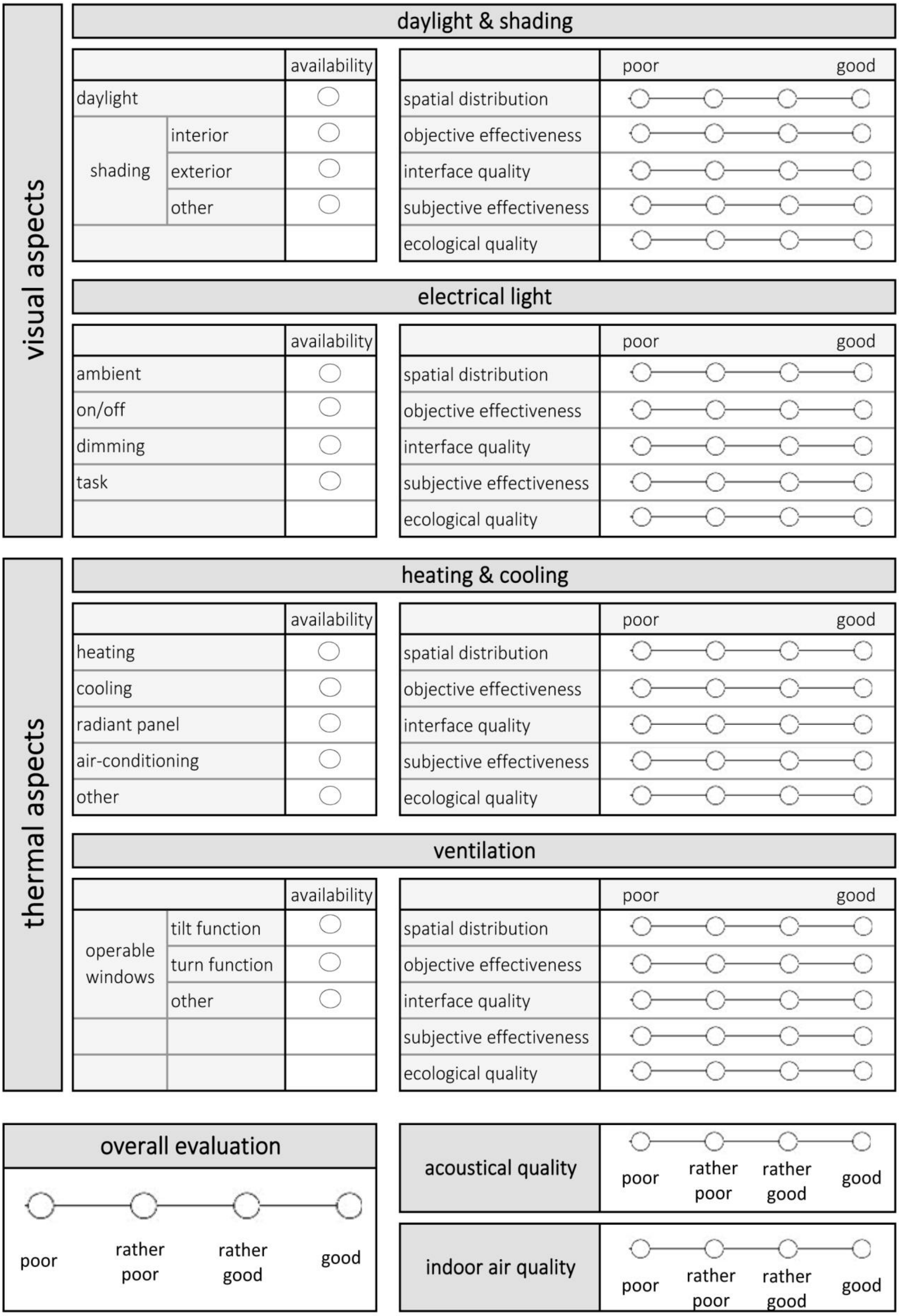

Figure 1. Structure of a room-level affordance evaluation protocol

The initial version of the protocol (Mahdavi et al. 2019) was structured based on a listing of such devices, whereby available devices had to be selected in a first step. In the present modified version, the protocol is structured in terms of categories pertaining to thermal and visual control domains (see Figure 1). It is thus no longer necessary to first select applicable devices. Specifically, the devices are currently evaluated in two main categories, namely the visual category (daylight and shading, electrical light) and the thermal category (heating, cooling, and ventilation).

The evaluation of the control devices includes two parts. The first part is concerned with the availability of the devices and their key properties. In the process, points can be assigned based on the device availability and the functions it offers. Part two address the effectiveness of the devices, whereby five key evaluation criteria are taken into consideration (Mahdavi 2019; Mahdavi and Berger 2019). We refer to these criteria as spatial distribution, effectiveness (both objective and subjective), interface quality, and ecological quality. A brief description of these criteria is provided in the following.

The spatial distribution criterion is intended to probe if and to which extent the devices allocated to a space provide a full and possibly uniform coverage of the respective services throughout the space. Evaluation with regard to this criterion can also consider the extent to which occupants can control their near surroundings.

The interface quality criterion pertains to the usability of control devices, that is, if the occupants can operate the devices in an easy and intuitive manner.

Regarding the effectiveness of the devices, two aspects are considered, addressing the objective and the subjective perspectives. The objective effectiveness would be ideally assessed via measurements of the relevant performance variables such as temperature or illuminance levels. Respective data could be obtained, if available, via BMS (building management system) or through short-term mobile diagnostics. Subjective effectiveness is intended to capture occupants' view on the performance of the devices and if these sufficiently achieve their intended task (Mahdavi 2019; Mahdavi and Berger 2019).

The final criterion, that is the ecological quality is meant to address the relative performance of devices in view of their estimated energy use and environmental impact. The related evaluation step can be admittedly challenging and could benefit from expert input. Generally speaking, passive control opportunities such as daylight availability and natural ventilation could be viewed as more in line with the ecological performance criteria. Moreover, certain types of active thermal control (for instance those involving radiant elements) may be considered to entail a higher potential with regard to ecological quality criterion. Needless to say, availability of operation data with regard to energy use or design stage data concerning life-cycle analysis could, if available, could contribute to the robustness of the respective evaluation process.

For each evaluation criteria, the perceived performance of the devices is evaluated using a typical qualitative scale with attributions "good", "rather good", "rather poor", or "poor". We adopted this arguably limited scale in order to keep the evaluation process simple. Nonetheless, we do recognize that such a scale affords only a rather coarse evaluation vehicle. To probe the potential benefits of alternatives, future efforts are intended to apply scales of higher resolution.

The AI of a zone or a room is obtained via aggregation of the points assigned to the individual devices. Note that additional weighting coefficients may be assigned to specific devices or rooms. Candidate weighting criteria include, for instance, the room size (e.g., net area) and/or its usage intensity by occupants.

PROTOCOL APPLICATION STUDIES

Approach

The aforementioned building affordance assessment method was tested in the course of a number of explorative case studies. In a previous effort, we explored the degree to which the evaluation results diverge if multiple people evaluate the same room using the developed assessment protocol (Teufl et al. 2020).

The main focus of the present contribution was to analyse the relationship of participants' overall evaluation of a room and its affordance index (total points of a space). This relationship can provide information on the consistency of the selected points and weighting factors. A key objective was to examine the relative share of points allocated to specific device categories and if this allocation scheme requires adjustments to more accurately reflect participants' overall evaluation of a space.

The selected point scheme for the deployed building affordance assessment protocol involved, in case of the effectiveness evaluation (part two), the qualitative evaluation of a control element as "poor", "rather poor", "rather good", and "good". These labels correspond numerically to zero, one, two, and three points respectively. As a result, in each device category, maximum 15 points can be received for the effectiveness (part two).

The assigned points for the availability diverge depending on the device category. Depending on the availability and functionality, a device receives a certain number of points. Table 1 shows the specified points awarded for the availability (part 1) of devices in different domains (i.e., daylighting, shading, electrical lighting, heating and cooling, ventilation). Hence, the distribution of the maximum number of points for part one is as follows: 9 points for daylight and shading, 8 points for electrical light, 15 points for heating and cooling, and 8 points for ventilation. As a result, the maximum number of points for a room (sum of part one and part two) amounts to 100.

In the course of aforementioned explorative case studies, a total of 356 different rooms were evaluated by multiple (mostly student) participants. 27 of them were female and 14 were male. The majority of the participants were between 20 and 30 years old. The evaluated rooms belonged to seven different building types. Table 2 presents, in more detail, the number of evaluated rooms in each specific building type.

Results

Figure 2 shows the relationship of participants' overall evaluation of a room and the corresponding affordance index. As mentioned before, the latter represents the total number of received points for a space. Figure 3 presents the distribution of the affordance index scores via a boxplot. The numeric values of the x-axis refer to an overall evaluation of "poor" (0), "rather poor" (1), "rather good" (2), and "good" (3).

Figure 4 illustrates the relationship between the overall evaluations (x-axis) and the corresponding points for individual device categories (daylight and shading, electrical lighting, heating and cooling, and ventilation). These relationships are illustrated via linear regression lines.

Discussion

The explorative application of the proposed affordance assessment protocol in the course of the aforementioned studies warrants certain conclusions. Already previous experiences with previous use of the earlier versions of the protocol suggest that participants could handle it conveniently and found it intuitive (Mahdavi et al. 2019). In the present paper we specifically address the relationships between (and consistency among) various constituent elements of the protocol.

One query pertains to the relationship between the obtained numeric value of the AI on the one hand and participants' overall qualitative evaluation of the assessed rooms. This relationship is illustrated in Figures 2 and 3. As Figure 2 shows, the Affordance Index results appear to be somewhat correlated with the overall qualitative evaluations (Pearson correlation coefficient = 0.5). Nonetheless, a widely distributed set of AI values maybe associated with a specific score in the four-point scale of overall evaluations. This circumstance is clearly visible in the boxplot visualization of Figure 3. Higher overall evaluation scores correspond to higher AI values. There is no overlap visible when comparing the interquartile ranges (IQR) for evaluation scores 1 and 2. And, in case of an overall evaluation score of 3 and 2, the interquartile ranges (IQR) overlap only slightly. However, this is not the case for the two lowest overall evaluation scores (0 and 1). In this context, it is important to mention that an overall evaluation score of 0 was only selected in case of 12 rooms. In comparison, the overall evaluation scores of 1, 2, and 3 were selected 71, 221, and 52 times, respectively.

We explored also the relationship between the overall evaluation scores on the one hand and the points received in the four device categories (i.e., daylight and shading, electrical lighting, heating and cooling, and ventilation (see Figure 4). The main motivation behind this exploration was as follows.

Table 1. Specified points for the evaluation of the availability (part one)

daylight and shading		**electrical light**		**heating and cooling**		**ventilation**	
daylight	3	ambient	2	heating/cooling	3/3	tilt function	3
interior shading	2	on/off	2	air-conditioning	3	turn function	3
exterior shading	2	dimming	2	radiant panel	3	other	2
other	2	task	2	other	3		

Table 2. Overview of the evaluated rooms

Building type	**Number of evaluated rooms**	**Total number of evaluated rooms**
Office	Office space (176), meeting room (28), kitchen (58)	262
Residential	Living room (5), kitchen (11), bedroom (15), bathroom (6), storage room (2), hallway (1)	40
Educational	Lecture room (17), study room (10), computer room (8)	35
Sport	Training area (3), changing room (4), bathroom (2)	9
Gastronomy	Eating area (3)	3
Health care	Patients room (1), staff room (1), meeting room (1)	3
Library	Reading area (4)	4

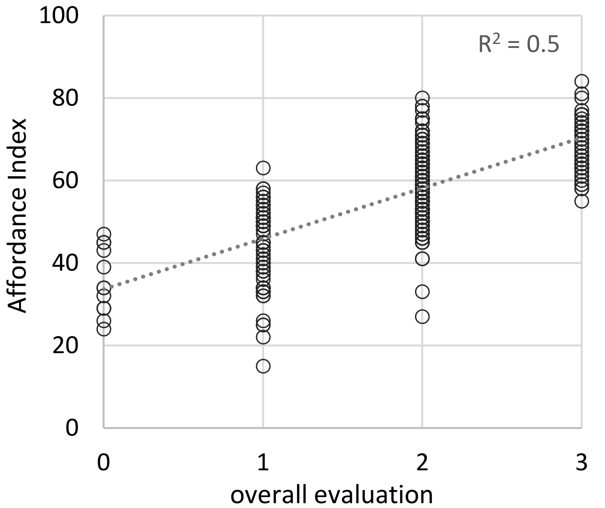

Figure 2. Relationship of affordance index and participants' overall evaluation of a room

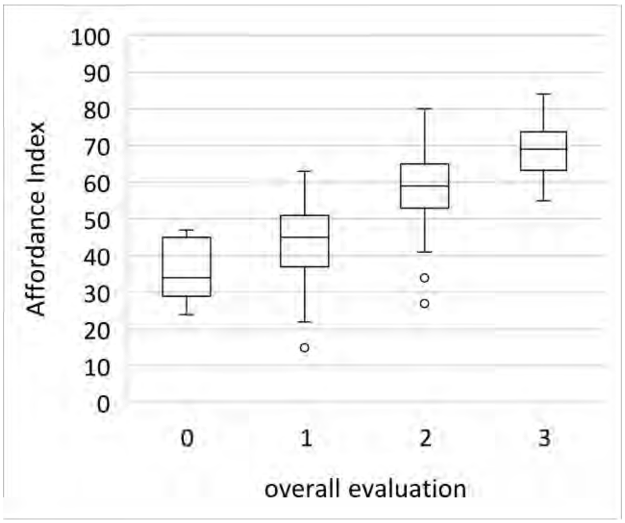

Figure 3. Boxplot of affordance index and participants' overall evaluation of a room

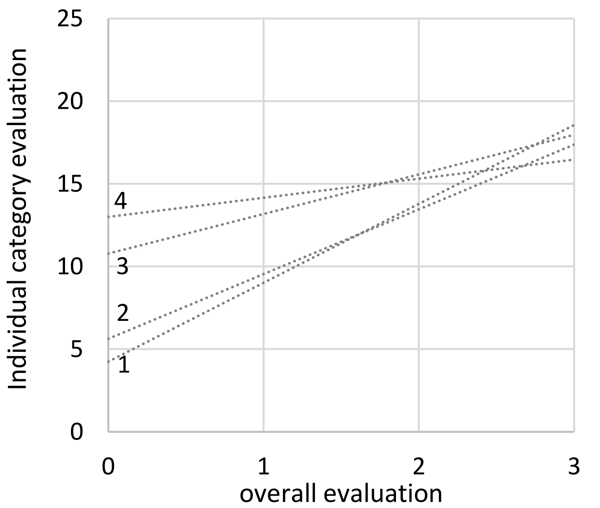

Figure 4. Relationship of participants' overall evaluation of a room and their points for daylight and shading (1; R^2=0.43), electrical lighting (4; R^2=0.08), heating and cooling (3; R^2=0.22), and ventilation (2; R^2=0.36)

Theoretically, the match between the AI values and subjective evaluations could be improved, if the assignments of credits to the four categories would take their relative implicit influence in the formation of the overall (subjective) evaluations of the assessed rooms into account.

As the regression functions in Figure 4 imply, the respective correlation degrees for the four categories vary. The highest correlation is in the category daylight and shading, followed by ventilation, and heating and cooling. The electrical lighting category shows no noteworthy correlation. These results will be processed together with those of ongoing assessment exercises to collect information on the relative influence of specific control device groups on people's overall subjective evaluations. In other words, we hope to identify the device categories that may be perceived by occupants as more important and thus could receive a higher weighting coefficient when compared to other device categories. As such, the respective findings could further improve the point scheme and weighting procedures and hence the entire evaluation protocol. In the course of such improvement efforts, we need also address the range of numeric values of AI and their association with descriptive categories such as "poor" or "good". The results thus far show that none of the evaluated rooms received an affordance index below 15 or above 84.

CONCLUSION

This paper explored recent improvement and testing steps concerning a previously developed building affordance evaluation method. This method makes use of an assessment protocol that can document the availability and effectiveness of indoor environmental control devices and systems in a room or building. A number of participants applied the protocol to existing rooms. Thereby, the potentials and limitations of the protocol could be examined in detail. To this end, 356 different rooms were assessed. The evaluated rooms were located in buildings belonging to seven different building types. Participants specifically assessed the availability and effectiveness of the control devices in these rooms. Moreover, they recorded their perceived overall evaluation of the rooms.

The focus of this contribution was to analyse the relationship of the participants' overall subjective evaluations with the respective numeric values of the Affordance Index. This index refers to the total number of received points for a room and was obtained by using the proposed building affordance evaluation protocol. This relationship can provide information on the accuracy of the allocated points and weighting factors. Hence, it would be possible to determine whether the fractions of points assigned to the different device categories need adjustments to further improve the reliability of the assessment protocol.

Generally speaking, the AI and the respective protocol appear to provide promising concepts and tools for the systematic inclusion of the highly relevant affordance aspect in building evaluation procedures. Nonetheless, additional studies with a large set of buildings (preferably various building types in multiple, climatically and culturally distinctive locations) and participants are required before the proposed tool could be embedded in common building evaluation and rating schemes.

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