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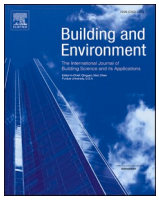

Profiling university students based on their acoustical and psychosocial preferences and characteristics of their home study places

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ABSTRACT

Understanding students' preferences of their study place, in particular acoustical and psychosocial preferences, is important to students' health and comfort. This study aimed to identify clusters of students with similar acoustical and psychosocial preferences, and to identify reasons for certain preferences of students in each cluster. A mixed-methods approach was applied, consisting of a questionnaire, which was completed by 451 bachelor students, and a field study conducted with 23 students from the same sample. The questionnaire data included among others acoustical and psychosocial preferences scores, while the field study data comprised interview transcripts, building checklists, and sound pressure level measurements. The questionnaire data were analysed using TwoStep cluster analysis to identify clusters of students based on their acoustical and psychosocial preferences. This produced five clusters of students that significantly differed in 14 variables, including preferences and perception of indoor environmental quality (e.g., noise from outside). Then, the field study data were analysed and categorised based on the five clusters of the students. The outcome explained the aspects associated with the acoustical preferences of students in each cluster. Building-related indicators such as the location of the building were found as an aspect that could affect the student's acoustical preferences. This study provides insight into the profiles of students based on their acoustical and psychosocial preferences, which are important for their health and comfort at their study places.

1. Introduction

Research has shown that university students spend their studying time (except lectures) at study places (i.e., informal study places), such as places at home or in educational buildings [1–3]. University students mainly perform highly cognitive tasks at these places, such as reading, writing, and problem-solving activities [4]. However, staying indoors for a long time is not beneficial to our health. This is because people are exposed to different environmental stressors while staying indoors. These stressors are related to indoor environmental quality (IEQ) factors, including indoor air quality, thermal quality, visual quality, and acoustical quality, which play an important role in occupants' health, comfort, and performance [5–7]. In several previous studies, the indoor environment of students' homes was found to be linked to their well-being [8–10]. Acoustical quality is one of the IEQ factors that can affect students' well-being and performance while studying or learning [11–17]. For example, students' heart rate and skin conductance levels decreased after being exposed to natural sounds (e.g., fountains and birds) in a study by Alvarsson et al. [18], indicating a calming effect.

Beckers et al. [1] found that university students tend to conduct individual learning activities at home because of their ability to control the environment. During the COVID-19 pandemic, two studies showed that university students tend to spend most of their time inside their homes during the weekdays (around 18 and 20 h), even more than before the pandemic (14 and 16 h) [8,9]. Also, in another study was found that most university students (74%) spend their study time at their homes, in 2021 and 2022 [19]. Moreover, the indoor physical environment of home study places was linked to students' stress during the pandemic [10]. Hence, well-designed study places that align with students' preferences and needs are significant for promoting health, comfort, and performance [20].

Students differed in their preferences and needs (IEQ and psychosocial) of their study places [19–22]. In another study, Cunningham and Walton [4] found that almost half of university students (52%) preferred to study at the university library because of the need for quiet study places. Similarly, Roetzel et al. [22] found that the acoustical quality is one of the most important IEQ-factor that students consider when selecting their study place at a university campus. Previous studies shed

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light on the adverse effects of background noise on students' health, comfort, and performance [23–25]. Also, students' acoustical perception is not only dependent on dose-related indicators, such as sound pressure level, but also on students' preferences, activities, and the context of the space [20–22]. Moreover, psychosocial preferences, such as privacy and the presence of others, may differ among students [19,26]. Harrop and Turpin [27] found a relation between students' preference for privacy and the preference for a quiet space at informal learning spaces. According to these studies, it seems that students' acoustical preferences have a relation with the psychosocial preferences, such as privacy. Nonetheless, there is a lack of knowledge of the interpersonal differences in acoustical preferences of occupants in indoor environments [28]. To better understand differences in acoustical and psycho-social preferences between individual university students, Hamida et al. [19] determined nine profiles based on the overlap between IEQ and the psychosocial preferences of study places. These profiles showed that students who have similar IEQ preferences can differ in their psychosocial preferences, and vice versa. Thus, it is important to consider both acoustical and psychosocial preferences while investigating the different clusters of students based on their preferences of study places.

To account for the individuals' differences in preferences and needs for IEQ, previous studies conducted TwoStep cluster analysis at different building contexts [19,21,29–33]. Ortiz and Bluyssen [29] revealed five clusters of home occupants based on their emotions, comfort, and locus of control at their homes. Bluyssen et al. [33] also found three clusters of university students based on their IEQ perception of their homes. Within the context of workplaces, the cluster analysis results from the study by Kim and Bluyssen [32] showed three clusters of office workers based on their IEQ comfort and self-reported health. Also, Ortiz and Bluyssen [30] found four clusters of office workers based on their IEQ preferences, and six clusters based on their psychosocial preferences during COVID-19. Furthermore, Eijkelenboom and Bluyssen [31] clustered the outpatient staff based on their IEQ comfort and preferences as well as psychosocial preferences and satisfaction at hospitals. They found six clusters based on the IEQ comfort and preferences, and three clusters based on the preferences and satisfaction of psychosocial aspects. Concerning the context of study places and learning environments, Zhang et al. [21] identified six clusters of primary school children based on their IEQ preferences in classrooms. The results from the study by Hamida et al. [19] revealed nine profiles of university students based on the overlap between IEQ and psychosocial preferences of study places. Hence, TwoStep cluster analysis shows its potential in identifying clusters of occupants based on their preferences and needs for the indoor environment. However, it does not allow for understanding the reasons behind the preferences of students in each cluster.

Ortiz and Bluyssen [29] applied a mixed-methods study design to facilitate the understanding of clusters with mixed data sources, including interview transcriptions and physical environment characteristics. Also, Hamida et al. [34] indicated that exploring the three levels of indicators (occupant-related (e.g., preferences), dose-related (e.g., sound pressure level), and building-related (e.g., absorption materials)) helps to better understand students' acoustical preferences and needs in an indoor learning environment. Therefore, this study answers the following two questions: 1) can university students be clustered based on their acoustical and psychosocial preferences of their home study places? and 2) can interviews with selected students from each cluster, building inspections of their home study places, and sound level measurements help to verify their acoustical preferences and their related aspects? It aims to explore the acoustical and psychosocial preferences of university students within different clusters based on the three levels of indicators.

2. Methods

2.1. Study design

A mixed-methods approach, as shown in Fig. 1, comprising of two parts, was applied in this study: 1) a questionnaire to identify the clusters of students, and 2) a follow-up field study to profile these clusters based on the building-related, dose-related, and occupant-related aspects that relate to their preferences. According to Creswell [35], the mixed-methods study design facilitates the researcher by explaining the quantitative results supported by qualitative findings. Hence, an explanatory sequential research design was adopted in which quantitative data from the questionnaire were collected and analysed first, followed by a field study in which mixed data (qualitative and quantitative) were collected and analysed. This was done sequentially to explain the outcomes from the questionnaire data with the results from the field study data.

2.2. Questionnaire

The questionnaire data analysis aims at clustering the university students based on the acoustical and psychosocial preferences of their study places. As described in the previous study [19], bachelor students (n = 451) of the Faculty of Architecture and the Built Environment at Delft University of Technology completed the '*MyStudyPlace*' questionnaire. The mean age of these students was 19.8 years (standard deviation (SD): 1.6 years), with 61% female and 39% male.

2.2.1. Questionnaire design

The '*MyStudyPlace*' questionnaire (Appendix A) is about exploring the university students' preferences of their study places. It consists of seven sections, including the preferences section, which is divided into the IEQ preferences (e.g., artificial light), the psychosocial preferences (e.g., bonding or identifying with the place), and the importance of IEQ-related aspects (e.g., control of shading). These sections help to explain the characteristics of each cluster. For the present study, the acoustical and psychosocial preferences that belong to that section were used, focused on the acoustical-related preferences, such as sounds from outside, and psychosocial preferences, such as privacy. These preference questions were stated as: 'Please rate on a scale from 1 to 10 (1: Not important at all; 10: Extremely important), the importance of each of the following aspects for your study performance at your study place – *(e.g., Sounds from outside)*'.

2.2.2. Data management and analysis

The questionnaire data were exported to SPSS version 26.0 software (SPSS Inc, Chicago, IL, USA). TwoStep cluster analysis, which is a segmentation method [36], was performed to cluster the students based on their acoustical and psychosocial preferences of their study places. This study included five variables as input which are preferences for sounds from outside, sounds from inside, presence and company of others, ability to control or adapt to the place, and privacy. After generation of the clusters, four validation steps were performed (according to Refs. [19,37]). Once the cluster model was validated, descriptive analysis was conducted to calculate the frequencies, percentages, and SD for different variables of each cluster. Also, the normality of distribution of these variables among the whole sample was tested. Then, Chi-square and ANOVA tests (for nominal and continuous variables, respectively) were applied to test whether these variables differ significantly differences between the clusters (the p-value had to be less than 0.05 for a significant difference). Besides, Phi coefficient was calculated to measure the effect sizes of the variables that were found significantly different among the clusters.

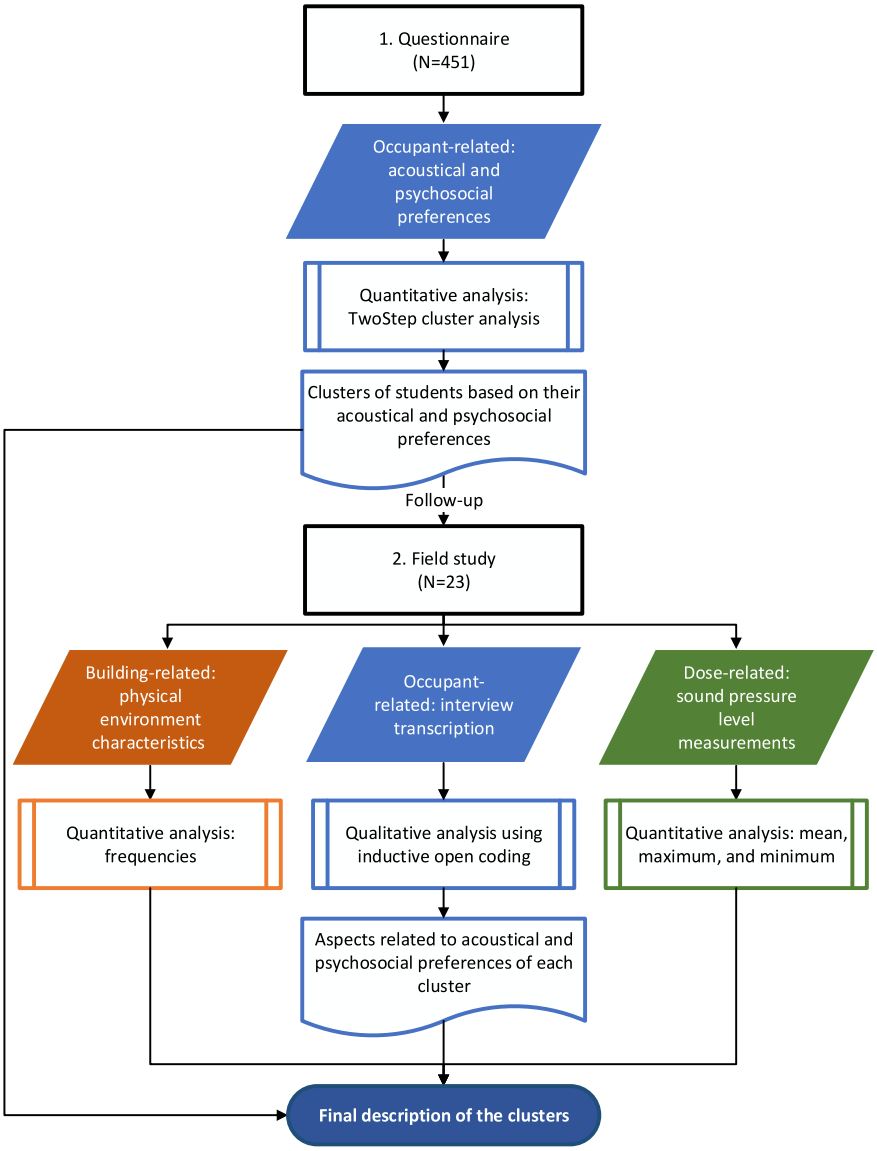

Fig. 1. Explanatory research design using a mixed-methods approach.

2.3. Field study

In the field study, three types of data, i.e., building-related, dose-related, and occupant-related, were collected and analysed.

2.3.1. Participants

In the 'MyStudyplace' questionnaire, the student was asked whether he/she was willing to participate in the field study. 95 (21.1%) students answered yes. They were contacted by email to invite them to participate in the follow-up study. 23 (5.1%) students accepted to participate in the field study. The mean age of these students was 21 years (SD: 1.5 years), with 15 students (65%) were female and 8 (35%) male. Since the majority of students who completed the questionnaire (74%) spent most of their study time at home [19], the field study was conducted at students' home study places. The study took place between November 2022 and February 2023.

2.3.2. Study design

The field study consisted of three parts: 1) a semi-structured interview with the student, 2) sound pressure level measurements at their home study place, and 3) an inspection of their home using a checklist.

To validate the preferences of the previously completed questionnaire, before the interview, the students were asked to answer a short questionnaire on eight preferences, identical to the question on preferences in the previously completed questionnaire (as explained in 2.2.1: ventilation, daylight, view to the outside, sounds from outside, sounds from inside, presence, and company of others, ability to adapt or control the place, and privacy).

The interview was done in English. An offline audio recorder (TASCAM DR-05X) was used to record the interview with the consent of the student. Each interview included the following questions:

1. How long have you used this study place?
2. Why did you choose this place as a study place?
3. According to the 'MyStudyPlace' questionnaire and the short questionnaire you completed before the follow-up study, you scored a '*lower/higher*' importance level for sounds from outside, and a '*lower/higher*' importance level for sounds from inside.
   - o Why do you think sounds from outside 'are/*became*' '*important/not important*'?
   - o Why do you think sounds from inside 'are/*became*' '*important/not important*'?

4. How should the optimal sound environment for your study place look like?
5. Which sound(s) do you prefer during your study-related activities at your study place?

The third question in the interview was personalized for each student based on their answers in both the '*MyStudyPlace*' questionnaire and the short questionnaire before the interview. For example, if the student scored a high importance level for sounds from outside in both questionnaires, the researcher (interviewer) asked the student (interviewee): "*Why do you think sounds from outside are important?*". On the other hand, if the importance of sounds from inside was scored lower than the answer in the previous questionnaire and was lower than 5, the question was stated as: "*Why do you think sounds from inside became unimportant*"?

The sound pressure level (SPL) is one of the dose-related indicators that may have an association with student's health and comfort in educational buildings [34,38]. Therefore, the SPL was measured at each home study place twice for 1 min with six intervals (10 s) using a sound level meter (Norsonic Nor 140). The sound level meter was placed on top of the study place desk (at a height of 120 cm, the height of a seated person's head).

A building checklist was used to investigate the building-related indicators of the home study places that can affect the acoustical quality [39]. The checklist comprised 15 sections, such as the presence of acoustic insulation materials, windows, and the presence of mechanical ventilation (Appendix B).

2.3.3. Procedure

Each of the 23 students received an individual invitation email that indicated the day and time of the interview. Additionally, the invitation included a consent form for the study at their home study place, the short questionnaire, and the interview questions. Students were asked to send both the signed consent form and the answers to the short questionnaire back to the researcher one day before the field study.

Each home visit took 30–60 min, starting with an interview with the student (15–30 min), followed by an inspection using the checklist (5–10 min), and finally, the SPL measurements (2–3 min).

2.3.4. Data management and analysis

Each of the audio recording files was transcribed into a verbatim transcription and anonymized by eliminating any personal data such as the student's name (if it was included). Then these transcriptions were initially and deductively coded (open coding) using ATLAS.ti 23 software. After that, the initial codes of each question were exported into a matrix that was created in an Excel file. This matrix consists of four columns that represent the four questions of the interview, and five rows (for each cluster) that represent the clusters' initial codes for each question. Then, focused coding (i.e., aspects) for each of the initial codes was done by abstracting the initial code and assigning a positive (+), negative (−), or neutral (/) meaning to each code, based on the student's answer. An example of the qualitative data analysis starting from initial coding to focused coding is presented in Fig. 2. Finally, a data structure was developed that includes columns representing the five clusters and rows that comprise the aspects (i.e. focused codes) related to the importance of sounds from outside and inside.

The SD and mean value of each SPL measurement were calculated for each home study place. Then the mean of the two measurements was calculated. After that, the median, maximum, and minimum of the SPL were calculated of each cluster. With regards to the building checklist, frequencies of several items were recorded of each cluster, such as the building type and building location. Besides, the minimum and maximum of different items were calculated, such as the study place height and gross area.

2.4. Ethical aspects

This study was approved by the Human Ethics Committee (HREC) of the Delft University of Technology on the 31st of January 2022.

3. Results

3.1. Questionnaire

TwoStep cluster analysis produced five clusters of students based on their acoustical and psychosocial preferences, as illustrated in Fig. 3. Each cluster has a name that consist of two parts, which represents the

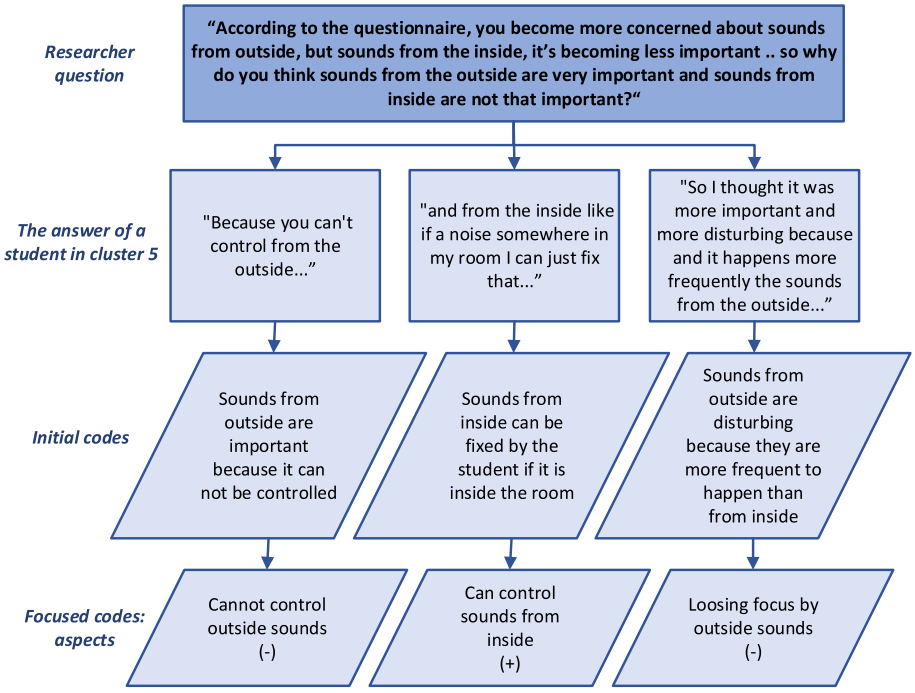

Fig. 2. An example of open coding of the answer to the preference question.

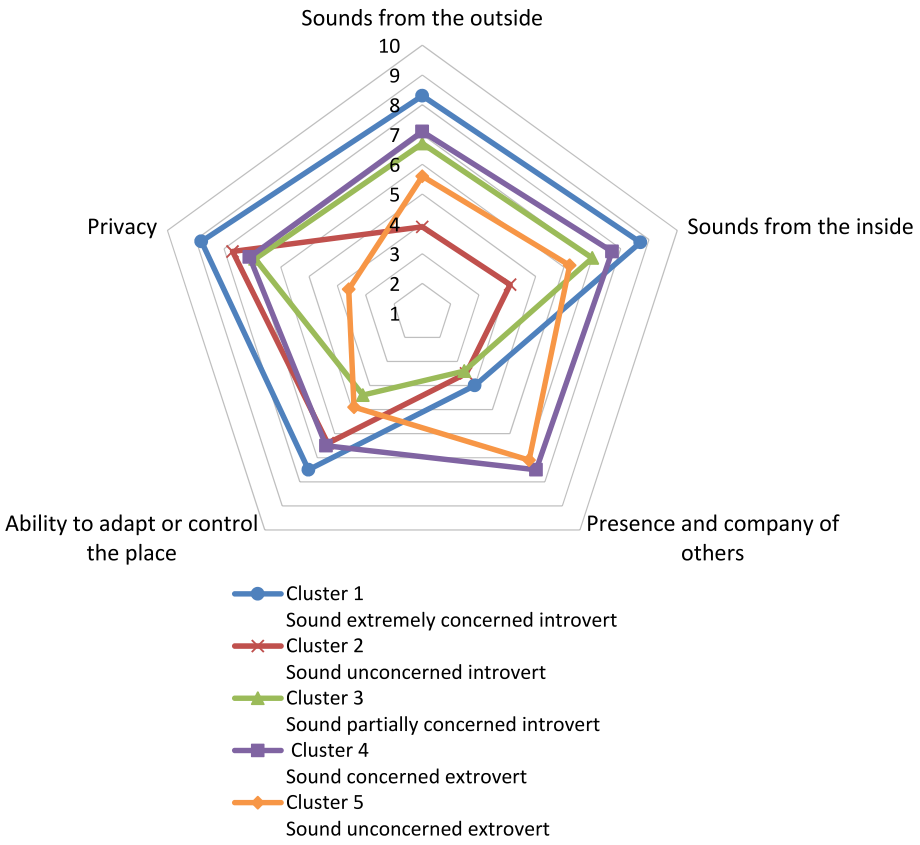

Fig. 3. Acoustical and psychosocial preferences of the five clusters of students.

acoustical and psychosocial preferences, respectively. The Silhouette measure was 0.3 and the validation results of the cluster model are presented in Appendix C. Each of these clusters has its unique preferences and characteristics as shown in Table 1. These five clusters showed statistically significant differences and high effect sizes for 14 variables, including study place ($p < 0.001$), sounds from outside ($p < 0.001$), sounds from inside ($p < 0.001$), presence, and company of others ($p < 0.001$), ability to adapt or control the place ($p < 0.001$), privacy ($p < 0.001$), and noise from outside dissatisfaction ($p = 0.017$). Other variables related to IEQ preferences, such as artificial light and smells showed also significantly differences. It was found that these variables were not normally distributed for the whole sample ($p < 0.001$). Although students of the five clusters differed in their acoustical preferences, all of them scored higher importance scores for sounds from inside than sounds from outside. Cluster 1 is the cluster most concerned with sounds from outside, sounds from inside, privacy and ability to adapt or control the place. Cluster 2 is the least concerned with sounds from outside, sounds from inside, and presence and company of others.

3.2. Field study

The field study was conducted with 23 students, of which four students from Cluster 1, two students from Cluster 2, eight students from Cluster 3, five students from Cluster 4, and four students from Cluster 5. The data comprised of transcriptions of the interviews, sound pressure level measurements, and the building checklist data.

3.2.1. Occupant-related indicators

The outcome of the interviews with the students represents the aspects associated with the importance of sounds from outside and inside, as well as the selection of the home study place's location. Tables 2 and 3 show the aspects (focused codes) assigned to the related customised interview questions.

In Table 2 '*too many outside sounds*' was sorted under the section 'sounds from outside are important', because it was related to the question: *why do you think sounds from outside are important*? Each aspect was than given a different level in terms of a neutral (/) or positive (+) or negative (−) meaning based on student's answer. Because each open question was customised based on the student's answer of each preference, there are questions that were not asked. For instance, both preferences 'sounds from outside are not important' and 'sounds from the inside are not important' were not asked to students in Cluster 1. Therefore, it is highlighted in Table 2 that these questions did not apply to that cluster, which are represented in cells with N/A which means not applicable.

It can be noted that '*Loud outside sounds*', '*Outside sounds are annoying*', and '*Losing focus by outside sounds*' were most frequent explanations for high concerns about sounds from outside by Clusters 1, 3, and 4. '*People from the inside sounds*' was the most frequent explanation for high concerns about sounds from inside by Clusters 1, 3, 4, and 5. '*Outside sounds are not distracting*' was a neutral aspect by one student in Cluster 2 and two students in Cluster 5. This explains the low concerns of sounds from outside by these two clusters. Music and natural sounds were the most preferable (positive) sounds and considered to provide an optimal sound environment. While music is indicated as positive by 15 students among the five clusters, three students indicated it as distracting, and thus negative. Similarly, silence was indicated as a positive sound environment by six students among Clusters 1, 3, 4, and 5, while it was indicated as negative by a student in Cluster 2. It can be observed that music, silence, and people sounds were indicated positive by some students and negative by other students.

Table 3 includes the 11 aspects that were associated with the selection of the location of the home study place. The three most frequently selected aspects were: '*Next to the window*', '*Room layout*', and '*View to the outside*'. Students in all five clusters indicated that the selection of their home study place location was based on the positive rated aspect:

Table 1
Profiles of the five clusters of students.

	Cluster 1:Sound extremely concerned introvert	Cluster 2:Sound unconcerned introvert	Cluster 3:Sound partially concerned introvert	Cluster 4:Sound concerned extrovert	Cluster 5:Sound unconcerned extrovert	p-value	Phi
Number (%)	70 (15.9)	78 (17.7)	87 (19.8)	116 (26.4)	89 (20.2)	–	–
Age mean (SD)	19.9 (1.3)	19.7 (1.1)	19.7 (1.6)	19.6 (1.5)	20.0 (2.1)	0.091	0.375
Gender N (%)						0.480	0.089
Female	44 (62.9)	42 (54.5)	50 (57.5)	76 (66.1)	57 (64.0)	–	–
Male	26 (37.1)	35 (45.5)	37 (42.5)	39 (33.9)	32 (36.0)	–	–
Study place N (%)						**P < 0.001**	0.462
Home	65 (92.9)	72 (92.3)	76 (87.4)	77 (66.4)	35 (39.3)	–	–
Educational building	5 (7.1)	6 (7.7)	11 (12.6)	38 (32.8)	53 (59.6)	–	–
IEQ preferences 1: completely not important; 10: extremely important- mean (SD)							
Sounds from outside[a]	8.3 (1.4)	3.9 (1.9)	6.7 (1.3)	7.1 (1.4)	5.6 (2.1)	**P < 0.001**	0.850
Sounds from inside[a]	8.7 (1.1)	4.1 (2.2)	7.0 (1.3)	7.7 (1.3)	6.2 (2.1)	**P < 0.001**	0.819
Smells	7.3 (2.1)	5.0 (2.3)	6.1 (2.1)	6.7 (1.8)	5.6 (2.2)	**P < 0.001**	0.448
Artificial light	6.9 (2.1)	6.0 (2.1)	6.0 (2.0)	6.5 (1.5)	5.7 (2.0)	**0.003**	0.381
Psychosocial preferences 1: not important; 10: extremely important – mean (SD)							
Presence and company of others[a]	4.0 (1.9)	3.5 (2.0)	3.4 (1.6)	7.5 (1.3)	7.1 (1.9)	**P < 0.001**	0.829
Bonding or identifying with the place	6.2 (2.3)	5.1 (2.8)	4.5 (2.2)	5.9 (2.2)	5.2 (2.5)	**P < 0.001**	0.466
Ability to adapt or control the place[a]	7.5 (1.5)	6.4 (2.2)	4.4 (1.8)	6.5 (1.5)	4.9 (2.1)	**P < 0.001**	0.589
Privacy[a]	8.8 (1.2)	7.7 (2.0)	6.9 (1.5)	7.1 (1.3)	3.6 (1.4)	**P < 0.001**	0.944
Importance of IEQ-related aspects 1: completely not important; 10: extremely important – mean (SD)							
Control of surrounding sounds	8.2 (1.4)	5.6 (2.5)	6.8 (1.7)	7.2 (1.5)	5.8 (2.1)	**P < 0.001**	0.564
Control of shading	8.3 (1.5)	6.1 (2.5)	7.3 (1.6)	7.4 (1.5)	6.8 (1.9)	**P < 0.001**	0.501
Control of room ventilation	8.0 (1.5)	6.2 (2.1)	6.9 (1.8)	7.0 (1.8)	6.5 (2.1)	**P < 0.001**	0.411
Control of room temperature	8.2 (1.3)	6.9 (1.8)	6.8 (1.5)	7.5 (1.7)	6.3 (2.2)	**P < 0.001**	0.427
IEQ Sound perception of study place in past 3 months - n (%within cluster level)							
Noise from outside dissatisfaction	28 (40.0)	19 (25.0)	21 (24.7)	28 (25.0)	14 (15.9)	**0.017**	0.167

Note.
[a] Input variable of the TwoStep cluster analysis.

'*Need for daylight*'. Note that '*View to outside*' varied within the same cluster; some students in Clusters 3 and 4 indicated it as positive and others as negative. Similarly, '*Facing the window*' was also varying in both Clusters 3 and 4. While one student in Cluster 3 indicated this aspect as positive, two indicated it as negative because of the other negative aspect '*Bothered by glare from the sun*'. Additionally, two students, one in Cluster 1 and one in 2, preferred studying in a private room (e.g., bedroom, private study room). This could explain the high concern for privacy of those two clusters.

3.2.2. Building-related indicators

The building checklist data of the home study places are presented per cluster in Table 5. Most of the students (n = 13) live in student housing, while a few live in private housing with roommates (n = 6) or parents (n = 4). Most of these buildings (n = 12) are situated in mixed commercial and residential areas. The number of levels of the building range from 2 to 18 floors, in which the home study place level ranges from ground level to 13 levels. Most study places are in the bedroom (n = 17) of which three of them are in a studio (bedroom, kitchen, and living area). In addition, most study places (n = 18) are placed close to the window. 18 of the study places have acoustical materials such as curtains or carpets inside the room. There were no acoustical materials at two home study places in Cluster 3, one home study place in Cluster 4, and two home study places in Cluster 5. All study places have a window of which only one in Cluster 5 has an unopenable window. Six home study places have mechanical ventilation, of which three of them are in Cluster 1, the others in Clusters 3, 4, and 5.

3.2.3. Dose-related indicators

Table 4 shows the SPL measurements results, of the 23 home study places per cluster, ranging from 25 to 49 dB(A). Clusters 1 and 2 have the lowest median (32 dB(A)), while Cluster 5 has the highest median (38 dB (A)). In addition, the interviewer investigated whether sounds from outside can be heard from inside during the interview. As a result, in 13 home study places, sounds from outside (such as birds or traffic) were heard indoors. This could mean that these home study places do not have sufficient sound insulation of windows or external walls. It can be noted that the visiting time of the 23 home study places differed due to the student's studying time at home. Out of the 23 field visits, 11 visits took place in the morning (9.00–12.00), eight visits took place in the afternoon (12.00–17.00), and four visits took place in the evening (17.00–19.00).

3.3. Descriptions of the five clusters

The profile of each cluster is described below, explaining per cluster the differences in occupant-related, dose-related, and building-related indicators between students of different clusters (from the questionnaire and the field study as illustrated in Tables 1–5).

3.3.1. Cluster 1: sound extremely concerned introvert

Cluster 1 has the smallest cluster group size (16%). This cluster

Table 2
Data structure acquired from interview analysis comprises the aspects related to acoustical preferences for each cluster, in which neutral:/, positive: +, negative: (frequencies).

Preferences	Aspects	Frequencies	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
			N = 4	N = 2	N = 8	N = 5	N = 4
Sounds from outside are important	Too many outside sounds	4	- (1)	N/A	- (2)		- (1)
	Loud outside sounds	10	- (1)	N/A	- (3)	- (1)	
	Outside sounds are annoying	7	- (2)	N/A	- (2)	- (3)	
	Outside sounds are muted	4	+ (2)	N/A	+ (1)	/(1)	
	Losing focus by outside sounds	7	- (2)	N/A	- (2)	- (3)	
	Hearing outside sounds when the window is open	2		N/A		- (2)	
	Facing roadside	4		N/A	- (2)	- (2)	
	People from outside sounds	6	- (1)	N/A	- (2)	- (2)	- (1)
	Need of quiet outside environment	3	+ (1)	N/A	+ (1)	+ (1)	
	Cannot control outside sounds	1		N/A			- (1)
Sounds from inside are important	People from inside sounds	10	- (2)	N/A	- (3)	+ (1) - (2) /(1)	- (1)
	Inside sounds are annoying	5	- (1)	N/A	- (3)		- (1)
	Losing focus by inside sounds	5	- (2)	N/A	- (1)	- (1)	- (1)
	Hearing inside sounds	7	- (3)	N/A		/(3)	- (1)
	No sufficient sound insulation	3		N/A	- (1)		- (2)
	Inconstant inside sounds	2		N/A	- (2)		
	No changes in inside sounds			N/A	/(1)	/(1)	
	Need of quiet inside environment	2		N/A	+ (1)	+ (1)	
Sounds from outside are not important	Outside sounds are not distracting	3	N/A		/(1)		/(2)
	It is a quiet outside environment	1	N/A		+ (1)		
	Not hearing outside sounds	3	N/A	/(1)	/(1)		/(1)
	Facing the entrance side away from the busy road	1	N/A			/(1)	
	People sounds	2	N/A	/(1)		+ (2)	
	Facing roadside	2	N/A			/(1)	
	Getting used to outside sounds	2	N/A			/(2)	
	Able to study with outside sounds	2	N/A	/(1)			/(1)
Sounds from inside are not important	Getting used to inside sounds	2	N/A	/(2)		N/A	
	People from inside sounds	2	N/A	/(2)		N/A	
	It is quiet inside environment	2	N/A		+ (1)	N/A	+ (1)
	Can control inside sounds	1	N/A			N/A	+ (1)
Optimal sound environment and sound preference	Silence (totally quiet)	7	+ (2)	- (1)	+ (2)	+ (1)	+ (1)
	Music sounds (e.g., piano, classical)	18	+ (3)	+ (2)	- (1) + (5)	+ (3) - (1)	+ (2) - (1)
	Traffic (e.g., cars)	4	- (1)	- (1)	- (1)		- (1)
	Machine sounds (e.g., ventilation, fridge)	5	+ (1)		+ (1) - (2)	/(1)	
	Natural sounds (e.g., birds, rain)	13	+ (2)	+ (1)	+ (6)	+ (2)	+ (2)
	People sounds (e.g., talking, working)	8	- (2)	+ (2)	- (3)	+ (1)	
	Applying sound absorption materials	5	+ (1)	+ (1)	+ (1)	+ (1)	+ (1)
	Controlling sounds	3			+ (1)	+ (1)	+ (1)
	Controlling window/door opening	4	+ (1)		+ (2)		+ (1)

Note: 1) an empty cell means a preference question was asked to students of a cluster but none of the students mentioned the aspect related to the question, 2) '+' means positive aspect, '-' means negative aspect, and '/' means neutral aspect, and 3) cells with N/A mean that the preference question was not asked to none of the students of a specific cluster.

accounts for the highest percentage (93%) in terms of spending study time at home. Cluster 1 students gave the highest importance scores for sounds from inside, sounds from outside, control of surrounding sounds, the ability to adapt or control the place, and privacy. In addition, students in Cluster 1 were most concerned with other IEQ preferences (e.g., artificial light and control of shading).

These acoustical preferences aspects remained important for the four students who participated in the follow-up study (scored above 5). This means that the field study resulted in the same preferences for Cluster 1 students. The interviewed students of Cluster 1 were mainly concerned with sounds from outside because of the negative aspects, such as '*Outside sounds are annoying*' and '*Losing focus by outside sounds*'. They were also highly concerned with sounds from inside for several negative reasons, such as '*Losing focus by inside sounds*', which conveys that inside sounds have negative impacts on their focus. They preferred to study in a quiet environment, with the presence of natural sounds from outside and low-level sounds from inside, such as music or sounds caused by the ventilation system. Cluster 1 was the cluster with the highest dissatisfaction with noise from outside (40.0%). It was also found that acoustical materials, including curtains and a carpet, were applied at these study places. Three of these places had mechanical ventilation, which one of these students accept to hear the sounds generated from the mechanical ventilation system. Furthermore, the four study places were all located in a private home. This confirms their high concerns about privacy. The selection of the home study place location was based on positive aspects such as the need for a quiet and private place next to or facing the window.

> Example quote from a student in Cluster 1: "*I do prefer if I don't hear too much from outside because this is really like my space, and I just want to be here in peace*".

3.3.2. Cluster 2: sound unconcerned introvert

Students in Cluster 2 were, similar to those in Cluster 1, more likely to spend most of their study time at their home, than students in the other clusters (92%). With regards to the acoustical preferences, students within this cluster scored the least importance level for sounds from outside and inside. Besides, Cluster 2 scored low importance levels

Table 3
Data structure acquired from interview analysis with the aspects for selecting the location of the home study place in each cluster, in which neutral:/, positive: +, negative: (frequencies).

	Aspects	Frequencies	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
			N = 4	N = 2	N = 8	N = 5	N = 4
Selection of home study place location	Preference of studying in a private room	2	+ (1)	+ (1)			
	Need of a quiet place	1	+ (1)				
	Next to the window	11	+ (1)		/(4)	+ (3)	+ (3)
	Need for daylight	7	+ (1)	+ (1)	+ (1)	+ (2)	+ (2)
	View to outside	9	+ (1)		+ (2)	+ (2)	+ (1)
			/(1)		- (1)	- (1)	
	Not close to the window	3	+ (1)		+ (2)		
	Bothered by glare from the sun	5	- (1)		- (2)	- (2)	
	Facing the window	7	+ (1)		+ (1)	+ (2)	
					- (2)	/(1)	
	Facing the wall	4	- (1)	+ (1)	- (1)	+ (1)	
	Room layout	10	/(2)	/(1)	/(4)	/(1)	/(2)
	Limitations of the room size	7			/(4)	/(3)	

Note: 1) an empty cell means the question was asked to students of a cluster but none of the students mentioned the aspect related to the question, and 2) '+' means positive aspect, '-' means negative aspect, and '/' means neutral aspect.

Table 4
Building and home study place characteristics of students per cluster.

		Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
		N = 4	N = 2	N = 8	N = 5	N = 4
Building type	Student housing (private room)	1	1	2	4	2
	Student housing (private studio)	3				
	Parents house			2	1	1
	Private apartment or house with roommate(s)		1	4		1
Location Building	Mixed residential area	1			2	
	Sub-urban with large garden			2	1	1
	Mixed commercial and residential area	2	2	4	2	2
	City centre, densely packed housing	1		2		1
Building's stories number: Minimum - Maximum		4–5	3–17	2–7	3–18	2–5
Home study place's story level (0 = ground level): Minimum - Maximum		2–3	2–13	0–5	2–4	1–2
Study place height (m) Minimum - Maximum		2.5–2.6	2.6–2.8	2.0–3.7	2.3–2.5	2.3–3.2
Study place gross area (m^2) Minimum - Maximum		19.2–27.2	6.8–8.2	9.9–49.1	8.3–24.5	14.2–23.2
Room type of the study place	Bedroom	1	1	5	5	2
	The living room opened to the kitchen			3		1
	Office room		1			1
	Studio (bedroom, kitchen, and living area)	3				
Study place location within the room	Close to the window and wall, at the corner	1	1	5	2	2
	Close to the wall, at the corner			1		
	Close to window and wall			1	1	1
	Close to window, wall, and door, at the corner				2	1
	Close to the window and wall, the centre of the room	1				
	Close to the wall, the centre of the room	2				
	Close to the wall and door, at the corner		1	1		
Acoustic absorption materials	Not applied			2	1	2
	Curtains	4	2	5	4	2
	Fibre tiles ceiling				2	
	Rug (part of the flooring)	1	1	1		
Wall covering	Paint	4	2	7	5	3
	Wallpaper			1		
Floor covering	Laminate flooring	3	1	7	5	3
	Synthetic smooth floor covering (vinyl)	1	1	1		1
Ceiling covering	Mineral fibre tiles				2	
	Paint	4	2	6	3	4
	Skylight (glass)			1		
	Wood			1		
Suspended ceiling: yes				1	2	
Number of windows (number can be opened); Minimum – maximum		1-2 (1–2)	1 (1–2)	1-3 (1–3)	1-2 (1–2)	1-2 (0–2)
Mechanical ventilation: yes		3		1	1	1

for other IEQ preferences, such as smells and control of shading and room ventilation.

Both interviewed students from this cluster remained unconcerned with sounds from inside (scored less than 5) because of neutral aspects, such as '*Getting used to inside sounds*', which means that inside sounds did not have effect (positive nor negative) on them. This cluster is unconcerned with sounds from outside because of neutral aspects: '*People sounds*' and '*Able to study in a quiet or loud environment*', meaning that outside sound sources and their volume do not affect the student's comfort negatively nor positively. This finding could explain that students in Cluster 2 were not highly concerned with sounds and the least concerned with the presence and company of others. While the students

Table 5
Acoustical environmental characteristics and SPL of the 23 home study places per cluster.

Cluster	Student ID	Sounds from outside can be heard from outside: Yes	1st SPL	2nd SPL	Mean SPL	Field visiting time
			LAeq (SD) [dB (A)]	LAeq (SD) [dB (A)]	LAeq [dB (A)]	
1	6		36 (7.1)	24 (2.8)	30	10.00–11.00
	11	X	34 (1.2)	32 (0.7)	33	9.00–10.00
	13	X	30 (2.0)	31 (1.7)	31	11.00–12.00
	23		34 (0.6)	34 (0.7)	34	16.00–17.00
	Cluster 1 Median: 32, minimum: 30, maximum: 34					
2	9	X	37 (2.2)	34 (1.2)	36	14.00–15.00
	20	X	27 (1.5)	27 (1.5)	27	17.00–18.00
	Cluster 2 Median: 32, minimum: 27, maximum: 36					
3	2		31 (1.9)	31 (2.8)	31	11.30–12.30
	3		35 (0.9)	35 (0.5)	35	16.00–17.00
	5	X	48 (5.7)	51 (5.8)	49	18.00–19.00
	7		30 (0.4)	30 (0.6)	30	13.00–14.00
	10		34 (1.3)	32 (0.4)	33	11.00–12.00
	14	X	39 (3.6)	36 (1.5)	38	17.00–18.00
	19	X	32 (2.4)	31 (1.2)	32	10.00–11.00
	21		31 (3.1)	38 (6.5)	35	10.00–11.00
	Cluster 3 Median: 34, minimum: 30, maximum: 49					
4	1	X	39 (1.3)	40 (0.2)	40	18.00–19.00
	4		33 (1.7)	32 (1.2)	33	10.00–11.00
	12		26 (2.6)	23 (0.5)	25	15.00–16.00
	16	X	29 (2.2)	31 (3.5)	30	10.00–11.00
	22	X	36 (0.3)	37 (0.8)	37	15.00–16.00
	Cluster 4 Median: 33, minimum: 25, maximum: 40					
5	8	X	40 (5.3)	41 (5.3)	41	11.00–12.00
	15	X	45 (5.8)	43 (4.6)	43	11.00–12.00
	17		30 (2.0)	29 (1.3)	30	15.00–16.00
	18	X	33 (1.4)	34 (1.7)	34	16.00–17.00
	Cluster 5 Median: 38, minimum: 30, maximum: 43					

Note: LAeq: A-weighed equivalent sound level.

do not prefer to study in totally quiet study places, they prefer the presence of natural sounds from outside and sounds made by people inside. Acoustical materials such as curtains were applied in both places. The two interviewees study in private home study places (a bedroom, and a private office room), of which one of them selected the study place because of the positive aspect: '*Preference of studying in a private room*'. This also could validate the finding that this cluster was the second highest cluster concerned with privacy.

> Example quote from a student in Cluster 2: "*Well, because I like sounds from inside, I don't mind if people are working or cooking or we have a really loud washing machine so you can hear it, but I don't really mind that*".

3.3.3. Cluster 3: sound partially concerned introvert

Most of Cluster 3 students (87%) spent most of their study time at home. These students scored intermediate importance levels for sounds from inside and outside. Also, they are partially concerned with other IEQ preferences such as control of room ventilation.

The eight interviewed students within this cluster re-scored high importance levels for both sounds from outside and inside (above 5), except for one student who scored them as a 5. The students who scored above 5 were concerned about outside sounds due to negative aspects, such as '*Facing roadside*' and '*Losing focus by outside sounds*', which conveys that outside sound sources could affect student's focus negatively. Besides, they were highly concerned with inside sounds because they get annoyed and lose focus by inside sounds, such as sounds made by people. The one student who became unconcerned with outside and inside sounds, indicated that both inside and outside sounds at the current home study place were quieter compared to the previous home study place. This could convey that this student no longer belongs to Cluster 3, but this student belongs to Cluster 2. All eight interviewed students preferred quiet environments where music and sounds made by people were not present. Additionally, they prefer to have control over the sounds as well as control over opening windows and door. This could explain the finding that Cluster 3 is one of the clusters that scored a relatively high importance level for control over the surrounding sounds. Two of the home study places lack acoustical materials, while five of them have curtains, and one has a carpet. Four of the interviewed students of this cluster were staying at a private apartment/house. This could explain the finding that the students were partially concerned with privacy and least concerned with the presence and company of others.

> Example quote from a student in Cluster 3: "*I think sounds just moves your concentration and it doesn't let you focus if you have too many sounds or if you have like sudden sounds, so I think that's why it's important*".

3.3.4. Cluster 4: sound concerned extrovert

Cluster 4 accounts for the largest cluster size (26%), in which one-third of students within this cluster spend most of their study time in an educational building. These students scored the second highest importance scores for both sounds from inside and from outside. Also, Cluster 4 is the second highest concerned with other IEQ preferences, including control of temperature and control of shading.

It can be noted that three out of the five interviewed students within this cluster became unconcerned with sounds from outside (scored 5 or 4). Lower importance of outside sounds seemed to be caused by changes in the home study place associated with building-related indicators, such as the location of the building. For instance, one of these students used to be exposed to traffic sounds, while the current home study place faced a quiet building entrance side. The two interviewed students that remained concerned with sounds from outside explained their concern because of negative aspects, such as '*Facing roadside*', and the positive aspect '*Need of quiet outside environment.*' These aspects convey that these students prefer to study in a quiet environment with the absence of traffic sounds from outside, which could have a positive effect on their comfort. Nevertheless, all five interviewed students remained concerned with sounds from inside because they need a quiet indoor environment to be able to focus. Regarding sound preference, the five interviewed students preferred to study in a quiet environment where natural sounds are present. Moreover, these students preferred to study in a place where they can control the surrounding sounds. This also supports the result that Cluster 4 was the cluster that scored the second highest importance level of control of surrounding sounds. Four of the home study places of

this cluster had acoustical materials. Four of the interviewed students were living in a student house where they shared facilities with roommates. Sharing facilities is in line with the finding that Cluster 4 students scored the highest importance level of presence and company of others.

> Example quote from a student in Cluster 4: "*But also like sometimes I put rain noises and stuff because that's like a really constant sound. And I have these like podcasts of one hour that are just like people studying and then you can hear like pages being flipped and that's also a very constant sound, so that helps*".

3.3.5. Cluster 5: sound unconcerned extrovert

Cluster 5 has the second largest cluster size (20%), of which more than half (60%) spent most of their study time in an educational building. Students within this cluster scored the second lowest importance levels for both sounds from outside and inside. They also scored the least importance levels for other IEQ preferences, including smells and artificial light.

Two out of four interviewed students became concerned with sounds from outside, and one of these two became more concerned with sounds from inside. The two students who remained unconcerned with sounds from outside because of neutral aspects, such as '*Outside sounds are not distracting*' or '*Not hearing outside sounds*', which could mean that outside sounds did not affect the students' focus positively nor negatively. On the contrary, the other two became more concerned with sounds from outside because of the negative aspect '*Cannot control outside sounds*', indicating the importance of control over outside sounds. Three of the interviewed students remained unconcerned with inside sounds because of the positive aspects '*Can control inside sounds*' and '*It is quiet inside environment*', which indicates that having control over inside sounds as well as studying at a quiet indoor environment fulfilled their acoustical needs, and therefore they were unconcerned with inside sounds. However, one of the interviewed students became more concerned with inside sounds because of too many inside sounds, such as noise made by people, which were not present at the previous home study place. Concerning the optimal sound environment, the four interviewed students prefer to study in a place where they can control the surrounding sounds. Also, they prefer the presence of music and natural sounds, such as rain and winds, at their study places. Besides, two of these home study places lack acoustical materials. It was observed that three of these students were living in a student house or a shared apartment where they share facilities with other roommates. This could support the fact that Cluster 5 was the most concerned with the presence and company of others. In contrast, students in this cluster were the least concerned with privacy.

> Example quote from a student in Cluster 5: "*With these sounds from outside, well, they're not really important because we have like one-sided glass. But now when I have my headphones on it doesn't really matter how much sound there is from outside, and when I put them of, I don't get distracted, so actually pretty OK with a bit of sound from outside*".

4. Discussion

4.1. Mixed methods for understanding the sound profiles of the five clusters

The outcome of this study showed that combining the results from the questionnaire and the field study contribute to the understanding of the sound profiles of the five clusters. This is in line with the conclusions drawn by Ortiz and Bluyssen [29] who highlighted that using mixed-methods with TwoStep cluster analysis is a valuable approach to better understand the profiles of different clusters. Moreover, several studies applied a mixed-methods approach to explore occupant's experience in an indoor environment. For instance, Hong et al. [40] found a relationship between dose-related indicators of different IEQ-factors (e.g., SPL) and students' productivity in a learning environment. This indicates the importance of combining dose-related indicators with occupant-related indicators. Also, Acun and Yilmazer [41] found that measuring only the SPL is not enough to understand student's acoustical preferences of study places. This finding is similar to the results from the present study. For example, while the median SPL of the four home study places in Cluster 1 was the lowest among the five clusters, students from this cluster were the most concerned with sounds from outside and inside. On the other hand, even though the highest median SPL was measured at the four home study places of Cluster 5, students within this cluster were least concerned with outside and inside sounds at their study places. Also, they were the least dissatisfied with sounds from outside.

In a study on sounds at home study places of the same university students who participated in the questionnaire of this study [42], dominant sounds identified were sounds caused by people inside, and natural sounds (e.g., birds and rain) outside. In this study, an explanation of their preferences for sounds was determined by associating different aspects to the importance scores of the acoustical preferences as well as to which sounds students prefer to hear. These aspects can be related to sound sources (e.g., people sounds), personal concentration (e.g., losing focus by sounds), perception (e.g., annoyance), building characteristics (e.g., no sufficient sound insulation), and building location (e.g., facing a roadside). Students in Clusters 1, 3, and 4 were concerned with outside sounds due to several negative aspects, such as loud outside sounds, getting annoyed by outside sounds, losing focus by outside sounds, and hearing people sounds from outside. On the contrary, students within Clusters 2 and 5 were unconcerned with outside sounds because of several neutral aspects, including being able to study in a quiet and loud environment and accepting to hear sound made by people. Also, the students within Clusters 1, 3, and 4 were highly concerned with inside sounds because of the negative aspect '*Losing focus by inside sounds*', while the students within Clusters 2 and 5 were not highly concerned with inside sounds because they were able to study with the presence of inside sounds.

The acoustical preferences of the interviewed 23 students, except for four students, were generally the same as their preferences pointed out in the '*MyStudyPlace*' questionnaire. In other words, the follow-up study enabled explanation of the preferences of the five clusters, of which the preferences of 19 students did not change. However, preferences might change over time due to several factors. For example, in a study on changes in preferences of different outpatient staff profiles in hospitals during COVID-19, by Eijkelenboom et al. [43], was concluded that preferences for the indoor environment can change over time due to changes in context. In this study, four students (one in Cluster 3, two in Cluster 4, and one in Cluster 5) moved to another study place within the same building or to a new building. As a result, their preferences changed due to changes in the sound sources (from outside and/or inside) at their home study places. The two students in Cluster 4 became less concerned with outside sounds because the previously identified '*annoying*' sounds (e.g. busy roads or people in the courtyard) were no longer present at the current home study place. Thus, these two students no longer belonged to Cluster 4, they could be categorised into Cluster 5. Similarly, a student in Cluster 3 became less concerned with outside sounds because the sound environment of the current home study place was quieter than the previous one. Therefore, this student could be placed into Cluster 2. In contrast, the student in Cluster 5 became more concerned with sounds from inside because of the exposure to noises made by people at the new home study place. Hence, this student could belong to Cluster 4.

Torresin et al. [44] also concluded that understanding occupants' sound preferences in a certain indoor environment is important. Therefore, in addition to scoring the preferences, it is important asking the students why they scored high or low importance scores for the acoustical preferences, and in this way determine the related aspects, another question could be which sound(s) they prefer to hear while they

are in a specific indoor environment.

4.2. Comparison with previous studies

From the nine profiles of the same university students (who were clustered based on IEQ and psychosocial preferences) [19], three profiles were highly concerned, three profiles were partially concerned, and three profiles were unconcerned with the sounds of their study places. While the acoustical perception from that study did not show a significant difference among the nine profiles, the five clusters in the present study differ significantly concerning their perception of noises from outside. This is similar to the results by Zhang et al. [21] who also found significant differences among the six clusters of primary school children at the classroom based on perception of the four IEQ factors including noise. Furthermore, they found that Cluster 6 was the least concerned with sounds and the least dissatisfied with noise. This is similar to the results of this study, in which Cluster 5 students were not highly concerned with sounds, and the least dissatisfied with sounds from outside.

Pertaining to the psychosocial aspects, Wu et al. [45], found that in general students prefer to study in private study places. In contrast, the five clusters showed significant differences in terms of psychosocial preferences. This study showed that while there are clusters of students (Clusters 1 and 4) who prefer to study in quiet spaces, those in Cluster 1 were highly concerned with privacy, and those in Cluster 4 were highly concerned with the presence and company of others. Cluster 4 students some interviewed students of Cluster 4 indicated that they prefer to hear other students' activity sounds, such as paper flipping sounds. These findings align with Zhang et al. [46], who also found that students have different preferences.

4.3. Limitations

This study is limited to the acoustical and psychosocial preferences for study places of bachelor students from the Faculty of Architecture and the Built Environment. Also, the number of participants of the follow-up study was not equal per cluster, but at least two participants per cluster participated. Four of these students moved to other study places which affected their acoustical preferences, and thus they could be categorised into another cluster. Note that the data from the interviews with the students per cluster cannot be generalised to describe the whole cluster. Nevertheless, these data provided insight into the aspects related to the acoustical preferences of students from different clusters as well as the contextual factors, such as the building location, that may affect their preferences.

Additionally, the measured dose-related indicators in the follow-up study were limited to the SPL, for example reverberation time or other IEQ parameters were not measured. Due to time limitations during the visit of each student's home study place, involving an interview and completion of the building checklist, the SPL measurement was limited to 1 min (with six time-intervals of 10-s), and was performed twice. Although the background sound during the whole field visit of each of the home study places was not varying in general, it is recommended for future studies to measure the SPL for a longer time, at least for 15 min as suggested by Puglisi et al. [47], but preferable for 24 h to get a better idea of the SPL variation during day and night.

Furthermore, the visiting time during the day differed among these 23 home study places. The occupant-related indicators were limited to acoustical preferences and evaluation of comfort. Further studies are needed to investigate the impacts of different sounds on health [48] and performance [12,49]. Nonetheless, the data acquired in this follow-up study made it possible to better explain the acoustical preferences for study places per cluster of students.

5. Conclusion

A mixed-methods approach was applied consisting of a questionnaire completed by 451 bachelor students and a field study conducted with 23 students from the same sample, to answer two research questions. The first question 'can university students be clustered based on their acoustical and psychosocial preferences of their study places?' was answered by identifying five clusters of students based on two acoustical preferences and three psychosocial preferences from the questionnaire. Several aspects (including comfort perception and IEQ preferences) were found to be significantly different among these clusters, including acoustical perception. Students who were concerned with sounds, as well as those who were unconcerned with sounds, differed in their psychosocial preferences, such as privacy and presence and company of others. The second research question 'can interviews with selected students from each cluster, building inspections of their home study places, and sound level measurements help to verify their acoustical preferences and their related aspects?' was answered by exploring the aspects related to the acoustical preferences of students from different clusters acquired from the field study, including the investigation of the three levels of indicators. It can be concluded that the field study led to a validation of the acoustical preferences and a better understanding of the aspects associated with these preferences of the selected students from each cluster. For instance, it was revealed that Cluster 1 students are highly concerned with sounds from outside and sounds from inside because of hearing the sounds people make, were perceived as annoying. On the other hand, Cluster 2 students were not concerned with sounds from outside nor inside because they are able to study with the presence of outside and inside sounds. Also, building-related indicators (e.g. building location) were associated with student's acoustical preferences. A mixed-methods study, including the investigation of the three types of indicators (occupant-related, building-related, and dose-related) based on a questionnaire, interviews, building checklists, and sound pressure measurements, seemed an effective approach to better understand the sound profiles of students. These profiles might help to explain the different acoustical preferences of students at home study places, and might help to better design study places for students of different clusters. Moreover, it is recommended in future studies to explore the different profiles of students from different faculties and universities since this study is limited to students at the faculty of Architecture and the Built Environment at the Delft University of Technology. This study was limited to the occupant-related indicators in terms of students' acoustical preferences and perceptions of their study places. Hence, it is recommended for future studies to test the effects of different sound sources on student's health, including physiological measurements (e.g., heartrate).

CRediT authorship contribution statement

Amneh Hamida: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **AnneMarie Eijkelenboom:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Philomena M. Bluyssen:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Questionnaire: 'MyStudyPlace'

Section	Sub-section	Instrument
Personal information	Age	–
	Gender	
Psycho-social aspects	Mood	OFFICAR, select one out of nine moods (e.g., cheerful) [44,46,47].
	Recently experienced positive events (e.g., wedding) and negative events (e.g., funeral).	OFFICAR, select either yes or no [44,46,47].
	Positive and Negative Affect Schedule (PANAS)	I-PANAS-SF, including five positive affects and five negative affects, on a scale of 1–5 (1: never, 5: always) [50].
Mostly used study place	Study place type	Select one of the three options: home, educational building, or other.
Preferences	IEQ preferences *Please rate on a scale from 1 to 10, the importance of each of the following aspects for your study performance at your study place, 1: Not important at all; 10: Extremely important* - e.g., temperature".	Eight aspects on a scale of 1–10 (1: not important at all, 10: extremely important) [30].
	Psychosocial preferences: "*Please rate on a scale from 1 to 10, the importance of each of the following aspects for your study performance at your study place, 1: Not important at all; 10: Extremely important* - e.g., privacy".	Nine aspects on a scale of 1–10 (1: not important at all, 10: extremely important) [30].
	Importance of IEQ-related items: "*Please rate on a scale from 1 to 10, the importance of each of following the items that would help you to study better, 1: Not important at all; 10: Extremely important* - e.g., lamp on my desk".	Eleven aspects on a scale 1 to 10 (1: not important at all, 10: extremely important) [30].
Comfort	IEQ perception: "*On a scale of 1 to 7, how would you describe the general indoor comfort of your MOST used study place in the past* 3 months*?* e.g., temperature satisfaction".	Eighteen aspects on a scale of 1–7 (1: dissatisfied, 7: satisfied [30,31,51].
	Control over IEQ factors: "*How much control do you personally have over the following aspects of your MOST used study place?* - e.g., ventilation".	Five aspects on a scale of 1–7 (1: not at all, 7: full control) [30].
	Psychosocial perception: *How satisfied are you with the following in your MOST used study place* - e.g., amount of privacy".	Five aspects on a scale of 1–7 (1: unsatisfactory, 7: satisfactory) [30].
Lifestyle	Physical activity	OFFICAR, select either yes or no [51].
	Smoking	OFFICAR, select one out of four options (e.g., no never, yes former, yes incidentally, yes daily) [51].
	Alcohol	OFFICAR, select one out of three options (e.g., yes daily, yes occasionally, no) [51].
Health and medical history	Suffering from diseases: "*Have you ever been told by your doctor that you are suffering from:* e.g., asthma"	OFFICAR, includes eighteen diseases, each disease is rated one out of three options: never, yes in the last 12 months, yes but not in the last 12 months [51].

Reference: [19].

Appendix B. Checklist

1. Building information	
Number of storeys of the building	(___)
Storey number of where the study place is located	(___)
Is the above story occupied by people?	☐ Yes
	☐ No
Ceiling height of the study place room	(___)m
The floor area of the study place rooms	(___)m^2
In which room does the study place is located?	☐ Bedroom
	☐ Living room
	☐ Kitchen
	☐ Other:_____
Where is the study place located?	☐ Close to window
	☐ Close to wall
	☐ Centre of the room
	☐ Close to the entrance
	☐ At the corner
2. Where is the building situated?	
Industrial area	☐
Mixed industrial/residential area	☐
Commercial area	☐
Mixed commercial/residential area	☐
City centre, densely packed housing	☐
Town, with or without small gardens	☐
Suburban, with large gardens	☐
Village in a rural area	☐
Rural area with no or few other homes nearby	☐
3. Are there any nearby (within 100 m) noise sources outside the building that might influence the indoor environment?	
None	☐

(*continued on next page*)

(*continued*)

1. Building information	
Car parking with a minimum of 50 places close to the building	☐
Busy road (at least part of the day)	☐
Highway	☐
Railway or station	☐
Subway	☐
Tram way	☐
Air traffic (up to 3 km)	☐
Water traffic	☐
Other entertainment or leisure	☐
School building	☐
Community buildings (halls, churches, etc.)	☐
Workshops	☐
Construction works	☐
4. Can you hear outside noise inside the study place?	☐ Yes
	☐ No
5. Are there any major indoor noise sources found inside the study place?	
No indoor noise sources	☐
Other occupants inside the same space	☐
Neighbours	☐
Machines (printers, computers, dryer/washing machines)	☐
Vibrations (fans, ducts)	☐
Elevators	☐
Other:_____	☐
Sound pressure level at home study place (for 1 min)	☐ _____
6. Is there any acoustic insulation applied?	☐ Yes: curtain, soft materials
	☐ No
7. Wall covering of the study place	
Wallpaper	☐
Enamel/gloss paint	☐
Dispersion/emulsion paint	☐
Wood/sealed cork	☐
Porous fabrics including textiles	☐
Stone/tiles	☐
Exposed concrete/plaster	☐
Other:_____	☐
8. The floor covering of the study place	
Carpet	☐
Wood	☐
Synthetic smooth floor covering (e.g., rubber, vinyl)	☐
Exposed concrete	☐
Tiles (e.g., stone, ceramic)	☐
Other:_____	☐
9. Ceiling covering of the study place	
Wallpaper	☐
Paint	☐
Synthetic material	☐
Mineral fibre tiles	☐
Wood/cork fibre tiles	☐
Gypsum/plaster	☐
Exposed concrete	☐
Other:_____	☐
10. Is there a suspended ceiling?	☐ Yes
	☐ No
11. Number of windows in the study place	Number: (___)
	Window-to-wall ratio: (___)
Can they be open?	☐ Yes, number: (___)
	☐ No
12. Is there mechanical ventilation in the study place?	☐ Yes
	☐ No
13. Study place furniture	☐ Chair: (arm, armless)
	☐ Desk
	☐ Cabinet
	☐ Desk lamp
	☐ Other: _____
14. Study place technologies	☐ Computer or laptop
	☐ Printer
	☐ Headphones
	☐ Other: _____

Appendix C. Predictor importance of the input variables for cluster model validation

Predictor importance	Final solution	First half solution	Second half solution
0.60–1.00	Privacy (1.00)	Privacy (1.00)	Sounds from inside (1.00)
	Presence and company of others (0.95)	Sounds from outside (0.84)	Presence and company of others (0.94)
	Sounds from inside (0.69)	Sounds from inside (0.70)	Privacy (0.76)
	Sounds from outside (0.68)	Presence and company of others (0.67)	Sounds from outside (0.69)
		Ability to adapt or control the place (0.61)	
0.30–0.59	Ability to adapt or control the place (0.35)	–	Ability to adapt or control the place (0.56)

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