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Which qualities should built environment possess to ensure satisfaction of higher-education students with remote education during pandemics?

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ABSTRACT

The COVID-19 pandemic has suddenly switched most education processes from face-to-face to remote mode, obliging millions of students to utilize their residences as study spaces. However, the characteristics of their residential built environments differ in terms of regional, social, cultural, and technological aspects. These differences should impact the students' performance and satisfaction which needs to be measured and studied. The present study aims to identify the effect of the residential built environment on students' satisfaction and academic performance during the COVID-19 pandemic. It was conducted in two countries, Kazakhstan (KZ) and Norway (NO), using a comprehensive online survey to gather data. An empirical assessment based on the structural equation model was employed to identify links between health, safety, and comfort of students' facilities and academic performance and satisfaction. We conclude that the built environment affects both satisfaction for remote education and their learning performance. Significant differences in readiness for remote education have been observed between urban and non-urban living areas: (1) The role of health-and-safety convenience seems to increase with the urbanization level of the respondents' living spaces; (2) in contrast, for non-urban residents, the provision of comfort facilities is dominant. In the meantime, an analysis "by regions" revealed that health-and-safety-related facilities in residences are more critical for remote education in Central Asia (KZ). In contrast, the comfort features of residences being more important for the students studying remotely in Northern Europe (NO). These results provide an understanding that would assist in improving remote education and preparing pandemic-ready living areas.

1. Introduction

1.1. General background on effect of COVID-19 pandemic on remote education

The COVID-19 pandemic has globally forced several groups of the society to stay home to impede virus propagation. Up to 1.5 billion learners have been generally affected by the closures by educational institutions [1]. Starting from March 2020, it was necessary to switch education into an online mode, forcing students to take all previously regular classes online. Therefore, students from various places and backgrounds had been required to adapt to new studying conditions that come with environmental, technological, and psychological issues [2]. For example, most teachers who participated in a survey stated that quarantine might result in psychological and health problems among students [3].

It was estimated that school children's body mass and risks of childhood obesity increased during quarantine in Mexico due to social

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confinement [4]. Also, COVID-19 pushed the digitalization process forward by testing the digitalization levels of all countries [5]. For example, due to lack of internet connection, only 200–250 students out of 500 could contact their teachers in a Turkish school, and the TV-broadcasted lessons are considered not good enough for the benefit of students [6]. Similarly, the Indian educational system has also faced with problems regarding internet issues and problems related to the ability and knowledge to use technologies for distance learning [7]. Finally, socioeconomic factors (e.g., type of school and income level) were influential during online education during COVID-19 lockdowns in Vietnam [8].

In Central Asia, due to the pandemic measures, the academic year of 2020–2021 started entirely in distance learning mode, with 2.5 million children being forced to study remotely in Kazakhstan [9]. Kazakhstani educational system faced several significant problems with online education: (1) 24,000 teachers and 185,000 students from low-income large families did not have laptops; (2) 2,000 teachers did not have internet access; (3) TV channels that broadcast asynchronous lectures were not available in 604 populated localities of the country [10]. According to World Bank, as of 2020 [11], Kazakhstan has been experiencing substantial education losses due to the COVID-19 pandemic. The gap between different student populations is widening due to differential access and the effectiveness of distance learning due to socioeconomic factors. School dropout increased due to student demotivation, i.e., for those who fall behind in education. COVID-19 would affect education in the long term forcing governments to react in order to recover from learning losses [11].

In Northern Europe, according to the Teaching and Learning International Survey (TALIS) conducted in 2018, Norway was less prepared for remote education in terms of information and communications technology (ICT) usage in teaching purposes, with only 46% of teachers having ICT separate or integrated with their education training compared to the average of the Organization for Economic Co-operation and Development (OECD) countries (56%) [12]. However, in terms of ICT availability, Norway was better prepared to face the online education format. Only 11% of principals have reported a shortage of digital technologies compared to the average of 25% among other OECD countries that participated in TALIS [12]. Indeed, 99% of Norwegians have internet access, and 99% of Norwegians under the age of 54 have a smartphone, meaning that Norway was ready to switch to remote education in terms of its ICT infrastructure [13]. A study investigating the effect of COVID-19 lockdowns on the performance of Norwegian bachelor's students during their capstone projects showed that students could achieve high grades. However, they got a negative experience of remote education due to a lack of social communication and of collaboration with other students [14].

1.2. Influencing factors for performance of remote education and satisfaction

1.2.1. Impact of COVID-19 pandemic lockdowns on higher-education students

Students' satisfaction with remote education and their academic performance due to the effect of the COVID-19 pandemic has been globally researched. For example, Lassoued et al. [15] focused on Arabic countries. They claimed that the main barrier categories for quality remote education are personal (e.g., lack of willingness to study), pedagogical (e.g., low preparedness level for distance studies), technical (e.g., poor internet connectivity, low ability to navigate through technical resources), and economic (e.g., lack of devices, inconvenient home environment). A typical home environment was perceived as an uncomfortable environment for remote studying due to the presence of small children, small living areas, and several people needing the same device for work/studying [15]. Other research studies in Jordan [16] and South Korea [17] have also reported similar technical (e.g., lack of robust connectivity to servers), financial (e.g., problems with purchasing special devices for study or pay for internet provider services), and logistic (e.g., dissatisfaction with remote studying insufficient preparedness level of both schools and students) issues.

Another study [18] that included worldwide respondents also highlighted dissatisfaction of students with online studying among countries with a lower standard of living, whereas those from countries with high standards were more satisfied with online studies during the pandemic. For example, online education in Spain has positively affected students' academic achievement and made their learning process more efficient [19]. In contrast, Pakistani students did not have a positive experience of remote education due to technical and financial issues related to internet connectivity [20]. The experience of Jordanian students was negative in terms of remote education as they claimed responsible imperfect digital study instruments for low academic achievements, they perceived online assignments frustrating, and did not overall recommend continuing online study [21]. Furthermore, remote exams were considered more stressful, where a lack of robust technical platforms and internet connectivity being the prime barriers to satisfaction with the exams [22].

Living districts might affect the quality of distance learning. In one study [23], rural students claimed to have an educational gap compared to urban students, addressing their perception of learning difficulties on basic concepts compared to students from urban areas. These could be easily linked to unhelpful environments, such as poverty and uneducated parental background [24]. Moreover, rural regions might not have proper ICT coverage, while lack of robust connection to the internet is one of the most critical factors in remote studying [16]. Additionally, the accessibility of technical resources and convenience have been addressed as other essential factors of student motivation [6]. Therefore, some policies have recommend adapting distance learning courses to regional situations, e.g., make radio broadcasting in a region where internet coverage is inadequate [25].

All in all, global lockdowns caused by the COVID-19 pandemic have impacted students from different countries worldwide, negatively affecting both their mental state and academic achievements. Most of the available literature claims that remote education from home brought dissatisfaction due to the lack of certain facilities. To the best of our knowledge, no study has yielded the effect of the residential built environment on the remote studying process. Apart from buildings' primary function of giving shelter, the residence should provide its occupants other environmental, economic, and social-functional facilities as well. For example, in our previous works, rapid sustainability assessment methods for the Kazakhstani construction sector have been developed [26,27]. Due to global lockdowns, building facility features are becoming more important, as residences start playing more roles in their residents' life as not only living but also a working and a studying place [28,29]. Nevertheless, in the light of recent pandemics, these values might change to the deterrence of virus spread, the benefit to the psychological health of the occupants, and the good air quality – those are becoming more important characteristics to the buildings [28,29]. Some of our previous works include the assessment of green building certification and/or rating systems, where it has been defined that these assessment methods are not fully ready to provide sustainable requirements for buildings during pandemics [29,30]. The following sub-sections will discuss how different residential facilities could affect the home studying process.

1.2.2. Health and safety at home

Health and safety in the built environment could be thoroughly described as measures taken against virus propagation, availability of greeneries and places for fitness as an aid to mental health, care of indoor air quality, natural ventilation, and optimal level of temperature and humidity to keep the resident in good well-being [29]. Measures against virus propagation may include the use of smart and innovative technologies (e.g., air regulators, CO_2 monitors), touchless technologies (e.g., motion sensors, voice control), other artificial intelligence (AI) technologies, auto-cleaning (along with a proper choice of cleaning agents to control volatile organic compounds emissions), and use of proper indoor materials that impede pathogen propagation [29,31–36]. A place for fitness activities may be deemed essential because physical activity improves mental state and relieves stress [22]. It has been observed in some studies that students who have reduced physical activity have become more stressed during remote studying [22]. Mental well-being is also claimed to be improved by plants' availability at homes, as they help people diminish their anxiety levels [37,38]. Quality indoor air is another important factor for achieving a healthy environment. Therefore, monitoring and controlling indoor air pollution and allowing natural ventilation is crucial for residents' well-being at home [29,32,39,40]. Places with high humidity combined with warm temperatures as well as places with low humidity combined with cold temperatures can intensify virus transmission, which brings a need to develop optimal levels of temperature and humidity in residential areas [41–43]. Besides, the indoor temperature of a study place is claimed to directly influence students' academic achievement and learning process [2].

1.2.3. Comfort at home

Comfort in the built environment can be evaluated through the availability of certain facilities and conditions such as light, a robust supply of electricity and internet, noise, technical resources, personal study space, and temperature & humidity. Several studies show that specific attention should be given to household information and communications technologies, as robust and high-speed connections can be claimed essential for pandemic periods for online study and work and for receiving all required services (e.g., medical consultations, deliveries) [29,44–46]. Having a personal space (for work/study and exercising) is critical for mental well-being [46,47]. Noise level is perceived to be one of the essential factors of comfort perception, as for many people, it is more important than ambient temperature, light, and air comfort levels [48]. Daylight is the final important factor for human health because of its implications on healthy sleep patterns, mood, and the prevention of pathogen propagation [49–52]. Noise and light particularly affect students' concentration and academic performance [2].

1.2.4. Student satisfaction and academic performance

Student satisfaction can be defined as a temporary attitude consequential after assessing students' educational practice, facilities, and amenities [53]. Thus, it is dependent on other latent variables, such as *academic achievement* and the facilities that the environment can offer. *Academic performance* demonstrates knowledge or skills established by the learning institution's curriculum, which is assessed via marks allocated by the educators [2,54,55]. The current research considers academic performance during remote education through academic achievements (i.e., grades) and the learning process level (i.e., acquiring new information). High academic achievements are claimed to define students' academic well-being, i.e., *academic achievement* as a variable impacting *student satisfaction* [55].

A review of the literature focusing on remote education during the pandemic period has addressed multiple issues impacting student motivation and performance in various regions. In the context of an educational system, the level of ICT service provision, social structure, and built environment are among the most significant factors [9–14, 56–59]. A descriptive statistical approach is dominant in most studies [9–14,56–59] attempting to describe these factors. However, these factors are interconnected.

The present study aims to identify and analyze the effect of the residential built environment on the students' academic satisfaction and performance during remote studying throughout the COVID-19 pandemic lockdowns on the example of students from Kazakhstan and Norway. This was measured through a structural model that includes health and safety, comfort features, the readiness of built environment, student satisfaction, and good academic performance, and their hypothesized relationships (Fig. 1).

2. Methods

2.1. Proposed research model

To start, to understand the main issues in remote education during the COVID-19 pandemic, a pilot study has been conducted. An internet-based survey has been administered among students studying online in Kazakhstan to collect information about difficulties and barriers that prevent students from comfortable studying at home. The respondents answered questions about their living space (e.g., area, number of people), challenges faced with the indoor environment, and the accessibility of study materials and resources. Two hundred responses were collected from different regions of Kazakhstan (61% from urban, 19% from suburban, 15.5% from rural, and 4.5% from highly rural areas).

This pilot study showed that people from rural areas are more dissatisfied with distance learning than those from urban areas due to the fact that their home conditions are not ready for and thus not well adapted to remote education. Almost all respondents from urban regions have a private space and a personal computer for comfortable studying, whereas the percentage of people not having these privileges increases from urban to highly rural areas. People from rural regions more often experience internet and electricity outages, more often get distracted from noise at home, and have lower access to necessary studying resources than students from urban areas. As a result, rural students do not seem to have a comfortable environment at home for studying online, which may lead to high dissatisfaction, feelings of depression, and a decrease in motivation as the surrounding home atmosphere may prevent them from proper studying and decrease their study performance.

The conducted survey also addressed the relationship between indoor environmental conditions and students' satisfaction during online studying. According to the obtained responses, there are multiple complaints about the home environment not being adjusted to acquire knowledge and properly study. Given the fact that distance learning is not even fully secured in Kazakhstan's urban settlements, people from rural regions face enormous difficulties. As a result, living in a remote area may make it extremely difficult to get the proper education level during online studying. This pilot study helped to understand the main aspects of comfortable studying at home: internet and electricity robustness, private study space and study devices (e.g., tablets, laptops, or PCs), and distractions (e.g., noise). Based on these preliminary findings and ideas obtained from the pilot study, the following survey instrument along with a full-scale research methodology was then designed.

The research framework developed (Fig. 2) is a proposed structural equation model (SEM) concept that describes the main inputs – health and safety, and comfort at home – into remote education. SEM is considered a measurement model that captures relations and quantifies and assesses unobservable 'latent' constructs. Since the latent variables cannot be described directly; therefore, observable variables are used to assess them. A minimum (possible) number of reliable variables is always preferable. Consequently, it provides an output of students' satisfaction with their learning process and academic performance. It also consists of the critical factors, related (observable) variables, and relationships developed based on an extensive literature review as well as experts' opinions on the topic. Multivariate analysis is used to establish the reliability of the evaluation (variables listed in Table 1). Each of the latent variables is described through at least two observable variables. The study's primary purpose is to investigate the direct relationship between the built environment and students' academic performance in the context of remote education. Therefore, several hypotheses have been tested:

Hypothesis 1. Building health & safety is an essential requirement for

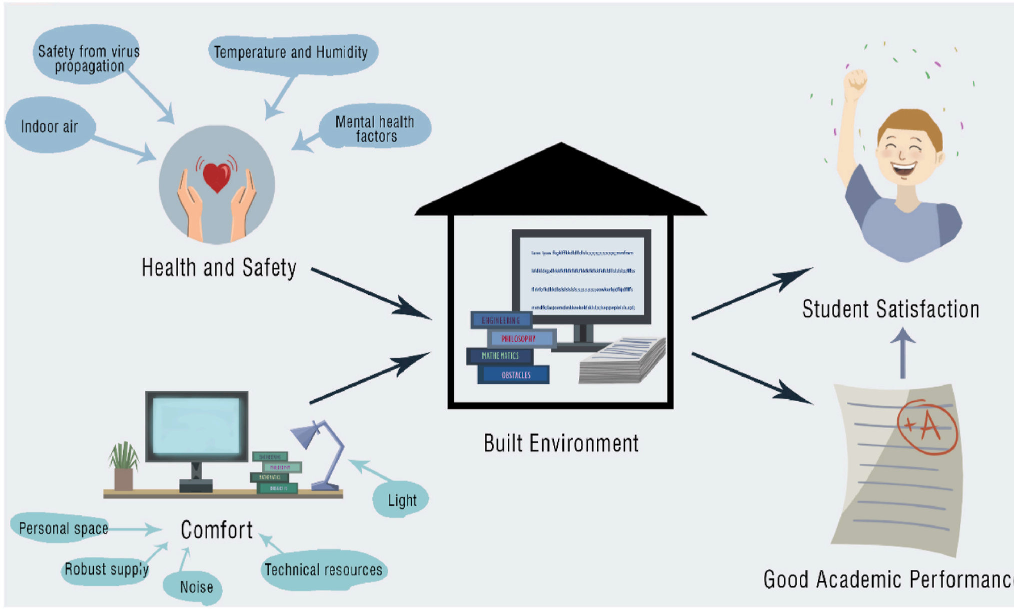

Fig. 1. Effect of features of residential built environment on student satisfaction.

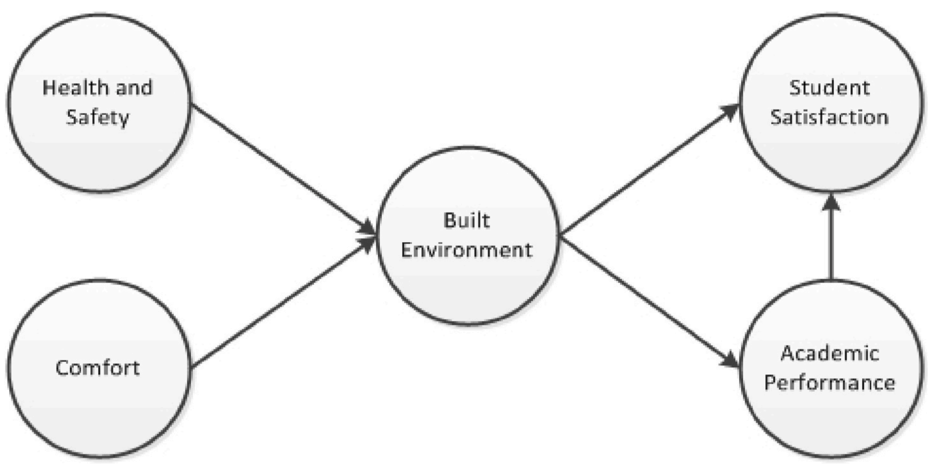

Fig. 2. Conceptual structural equation model (SEM).

a built environment to facilitate satisfactory remote education

Hypothesis 2. Building comfort is an essential requirement in a built environment to facilitate satisfactory remote education

Hypothesis 3. A residential building environment with adequate health & safety and comfort facilities provide better student satisfaction for remote education

Hypothesis 4. A residential building environment with adequate health & safety and comfort facilities leads to better academic performance

2.2. Measurement model: data collection, analysis, and testing

The survey instrument was developed to define the relationship between the factors that impact remote education satisfaction, academic performance, and residential facilities for studying. The extended survey contained 33 questions, from which 16 are directly related to the proposed SEM model. The assessment was based on a 5-point *Likert scale*, ranging from “totally agree, score 1” to “totally disagree, score 5.” The other 17 questions were of either auxiliary, helping to identify more details about the built environment (i.e., presence of certain residential facilities) or demographical nature (e.g., age, level of education, types of the living environment). Nazarbayev University International Research Ethics Committee has previously approved the research instrument.

In order to estimate the proposed model for remote education and test its validity and reliability, Partial Least Square (PLS) SEM approach was applied [60]. SEM is a multivariate statistical analysis technique used in inferential statistics to analyze structural relationships and test hypotheses. Defined by linear inner (relationships between the latent variables) and outer (relationships between the latent variables and their measures) model equation sets, it is a statistical approach that establishes hypotheses and studies the connection among latent and observable variables [61–63]. SmartPLS software has been used to estimate the proposed structural equation model for the PLS estimation due to its convenience in use and clear outputs [60,64]. Thus, the PLS approach provides results to test the reliability and validity of the proposed model, regression weights for all paths (demonstrated as arrows in Fig. 2), and therefore, helped to test whether the hypothesis regarding the relations between the model constructs should be accepted.

Table 1
Latent and observable variables.

Latent variables	Observable variables	Measuring Questions
Health and Safety (HS)	HS1. Safety from virus propagation	I am feeling safe from virus propagation at my home.
	HS2. Mental health	My mental well-being is in a good state for qualitative online studying.
	HS3. Indoor air	The air at my home is very comfortable.
	HS4. Humidity	The humidity level at my home is very comfortable.
	HS5. Temperature	The temperature level at my home is very comfortable.
Comfort (C)	C1. Light	The level of light at my home is very comfortable.
	C2. Noise	The noise level at my home is very comfortable.
	C3. ICT coverage	ICT coverage at my home fully satisfies my needs.
	C4. Access to necessary technical resources	I have full access to the necessary technical resources for my studies.
	C5. Comfortable study space	My study space at home has full comfort
Academic performance (AP)	AP1. Better learning	I receive better learning during remote education.
	AP2. Higher achievement	I get higher academic achievements during remote education.
Student satisfaction with remote education (SS)	SS1. Overall satisfaction	I am satisfied with the remote education process at my home
	SS2. Fulfillment of expectations (if any exist)	The remote education process fulfills my expectations on my success.
Built environment (BE) readiness to facilitate remote education	BE1. BE provides students with required health and safety measures	I feel that my home provides me with all health & safety measures during
	BE2. BE provides students with comfort for remote education	I feel that my home provides me total comfort for remote education.

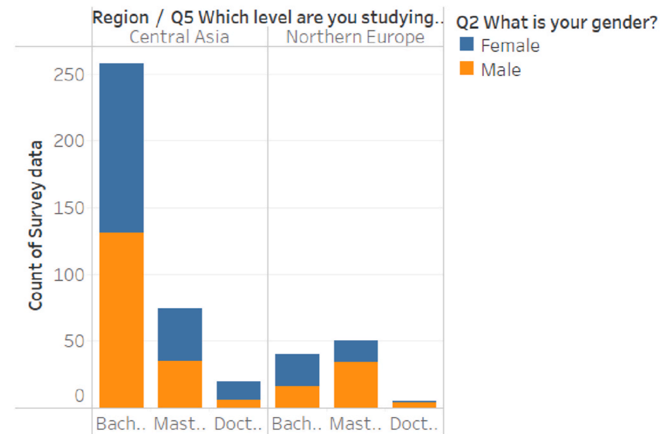

Fig. 3. Representation of survey respondents by education level and gender.

3. Results and discussion

The results and discussions are presented in three sub-sections: (1) descriptive findings present the general findings from the survey that are related to demographics, living conditions, etc.; (2) assessment of SEM performance and validity, where we check and approve the obtained results using SEM; which is followed by (3) implication of SEM model, where general discussions on SEM model results are conducted, after which it is going deeper into (4) analysis by living regions (Norway vs. Kazakhstan; urban vs. non-urban).

3.1. Descriptive findings

The survey responses have been anonymously collected through internet surveying from the students involved in remote studying during the COVID-19 pandemic, and 509 respondents have participated. Among the collected data, 490 were found satisfactory to use for further processing. In rare cases where some data were missing, they were replaced with mean values. The minimum sample size fits the requirements stated by Hair et al. [64]. Regarding demographics and living conditions (Fig. 3, Table 2), the majority of the respondents were from Central Asia (72%), the presence of females (51%) and males (48%) were comparable. Around 70% of the respondents were studying bachelor's degree, and the prevailing age range was18–21 (52%).

The living conditions of the respondents have been queried to understand the general characteristics of the data set (Table 2). Most of the surveyed students were from urban areas. More than half of the respondents lived in apartments larger than 50 sq. m. The number of residents sharing a building facility was five or more in 29% of the cases, whereas only 11% lived alone.

The overall satisfaction with remote education prevails in all living areas and building types (Fig. 4 a, b; neutral opinions were not presented), the satisfaction level being the highest for those residing in dormitories. A combination of both "strong satisfaction" and "satisfaction" levels was nearly the same for all three building types – varying from 30% to 32%. Interestingly, the most dissatisfied students are those who live in single-family houses and apartments. The most substantial dissatisfaction with remote education (70% answered strongly dissatisfied or dissatisfied) was obtained for students from highly rural areas. At the same time, urban located students are the most content group with remote education – with the lowest level of dissatisfaction, which can be still considered high (in total, 49% answered strongly dissatisfied or dissatisfied) and the highest level of satisfaction (in total, 34% of students strongly satisfied or satisfied).

The proposed model for remote education measured student satisfaction by two paths (built environment readiness and academic performance). Moreover, the satisfaction is reflected and measured by two variables (overall satisfaction and fulfillment of expectations). Besides, academic performance is also reflected and measured by two variables (better learning, higher achievement, i.e., grades). In Fig. 5, these four endogenous variables are illustrated. By looking into the urban student group and at the 5-point *Likert scale* assessment, the satisfaction rate was observed as low. The same can be observed for student achievement and fulfillment of expectations. However, when it comes to "better learning", the 5-point *Likert scale* assessment shows high scores for scales 1 and 2. Thus, it can be concluded that student learning is relatively high compared to satisfaction rate and achievement. In other words, students have reported that they are not satisfied; they expected more from remote learning and felt that they achieved less. This conclusion is valid for student groups from both studied areas (Central Asia, i.e., Kazakhstan, and Northern Europe, i.e., Norway).

The descriptive findings (Fig. 6) indicate that students (in total) feel virus-safe when they live in buildings with good air, humidity, and temperature conditions. However, they feel that their buildings during remote education are not providing them good mental well-being. The same for comfort features of their buildings (Fig. 7), students indicate that their built environment offers good ICT coverage and light conditions. However, students also indicate that their built environment does not offer comfortable studying space and the noise level is uncomfortable.

The number of dissatisfied students with remote education (Fig. 8, depending on the characteristics of residential facilities such as having access to greeneries, a place to do exercise, and a personal computer

Table 2
Demographics and living conditions for the survey participants of the present study.

Sex	Female	51%	Number of people sharing the same residence	1		11%
	Male	48%		2		22%
Level of education	Bachelor	69%		3		20%
	Master	26%		4		18%
	Doctoral	5%		5 or more		29%
Age	18–21	52%	**Frequency of electricity and/or internet supply failing at the residence**	Urban	Very rarely	68%
					1-2 times per week	17%
	22–24	29%			3-5 times per week	8%
					6-7 times per week	3%
	25–27	10%			Everyday	5%
				Suburban	Very rarely	66%
	28 and more	9%			1-2 times per week	20%
					3-5 times per week	9%
Area of the residence	Less than 25 sq. m.	16%			6-7 times per week	4%
					Everyday	1%
	25-37 sq. m.	13%		Rural	Very rarely	74%
	38-50 sq. m.	17%			1-2 times per week	15%
	More than 50 sq. m.	54%			3-5 times per week	3%
Living area	Urban	74%			6-7 times per week	3%
	Suburban	15%			Everyday	5%
	Rural	7%		Highly rural	Very rarely	55%
	Highly rural	4%			1-2 times per week	10%
Building type	Apartment	63%			3-5 times per week	15%
	Dormitory	7%			6-7 times per week	10%
	Single-family house	30%			Everyday	10%

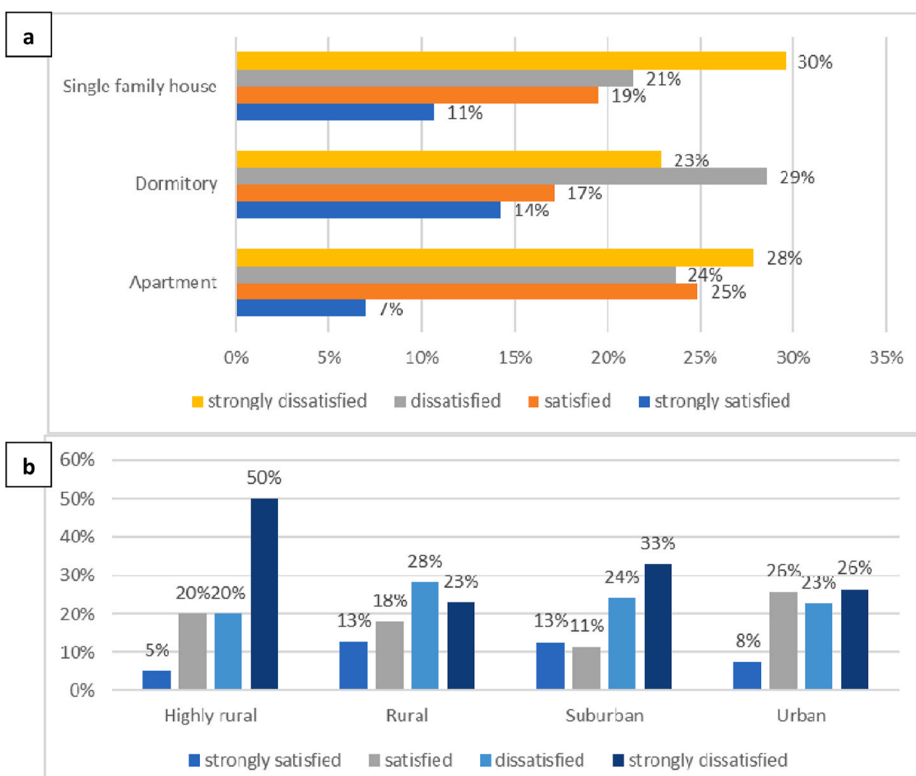

Fig. 4. Percentages of student satisfaction with remote education depending on the type of (a) residential building and (b) living area.

with a personal study space) shows that students' dissatisfaction is lower when they have all the listed amenities. Thus, it can be stated that owning greeneries, a particular spot for fitness, a personal computer, and a study space would lead to higher levels of satisfaction with distance education. The most significant effects on distance learning dissatisfaction could be identified as lack of personal computers, followed by a lack of personal study space.

One hundred and forty-four respondents have provided additional comments on the issues they face during the remote education process. Ninety-seven emphasized that they had significant comfort issues at home, including tight space at home, lack of personal study space, insufficient services of internet and electricity, noise, light issues, and unavailable technical resources necessary for studying. Fourteen students mentioned that their homes' health and safety level is not appropriate for their comfortable education, i.e., the air is too dry and hard to ventilate naturally, or they do not have a proper spot for exercising. Three additional comments were received about the overall health level worsening during home education. Interestingly, three

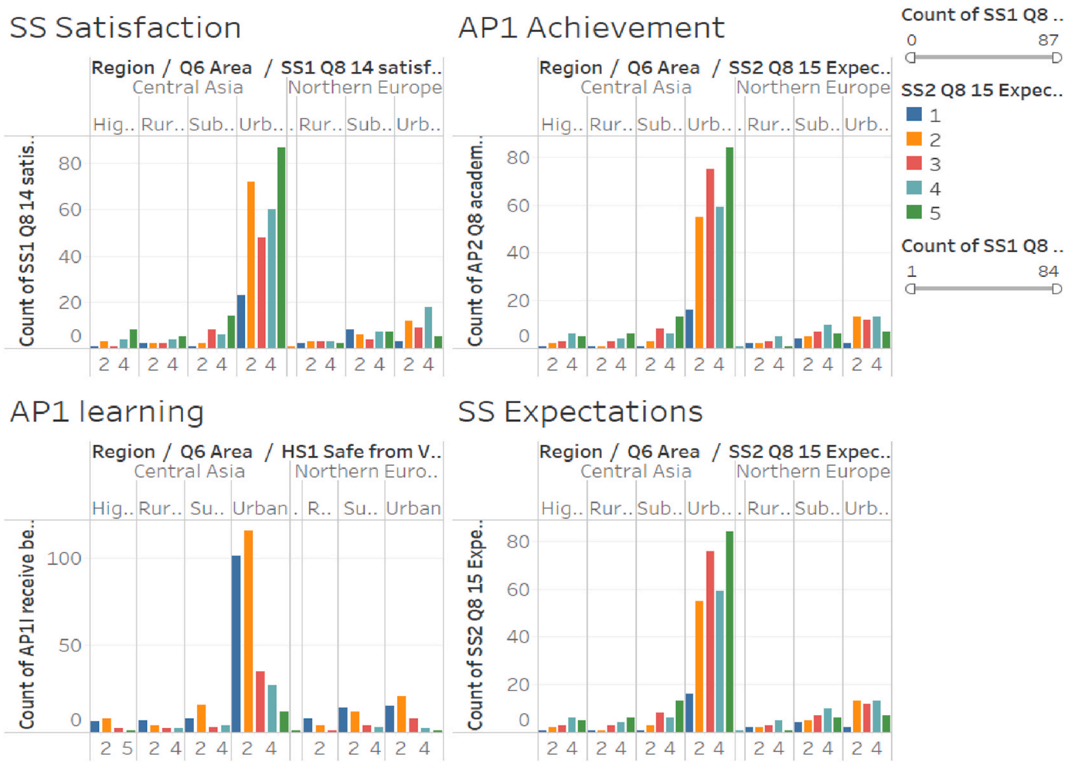

Fig. 5. 5-Point Likert scale assessment for (a) student satisfaction, (b) achievement, (c) better learning, (d) fulfillment of expectations.

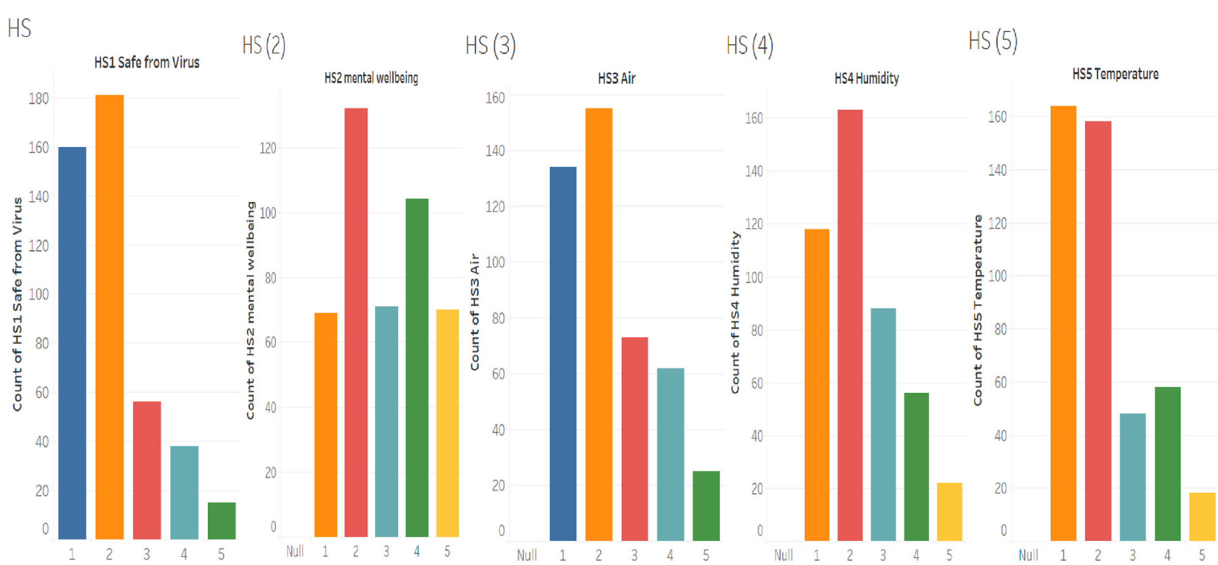

Fig. 6. 5-Point *Likert scale* assessment of health and safety variables (n = 490 responses).

students were dissatisfied with the tremendous increase in screen time, which may lead to eye health problems. Twenty-five respondents stressed in the comments that they are dissatisfied with the remote education process at home (including exam or attendance policies), and they would like to go back offline to the university campus. Five respondents were also dissatisfied with the lack of communication.

3.2. Assessment of SEM performance and validity

Following the PLS procedures, the proposed SEM model's outer weights and outer loadings, and descriptive statistics are summarized in Table 3. An outer loading shows the relationship between the latent indicator variable and its reflective construct. A value of 0.7 or greater means that the latent and manifest variables are strongly correlated, i.e., the manifest variables are good representatives of their related factors [65]. Most of the loading scores (except HS1, HS2, HS5, C3, C4) are higher than 0.7, meaning that the observable variables are well structured, and their relationships with the respecting latent factors are empirically supported. The reasoning behind lower shared variance (e.g., HS1, HS2, and C4) could be an unfitting indicator or improper wording of the survey question. If the manifest variables are reflectively connected to their related factors, the unidimensionality of the blocks should be checked. For this purpose, as recommended by Fornell and Larcker [66] for structural equation modeling with the PLS approach,

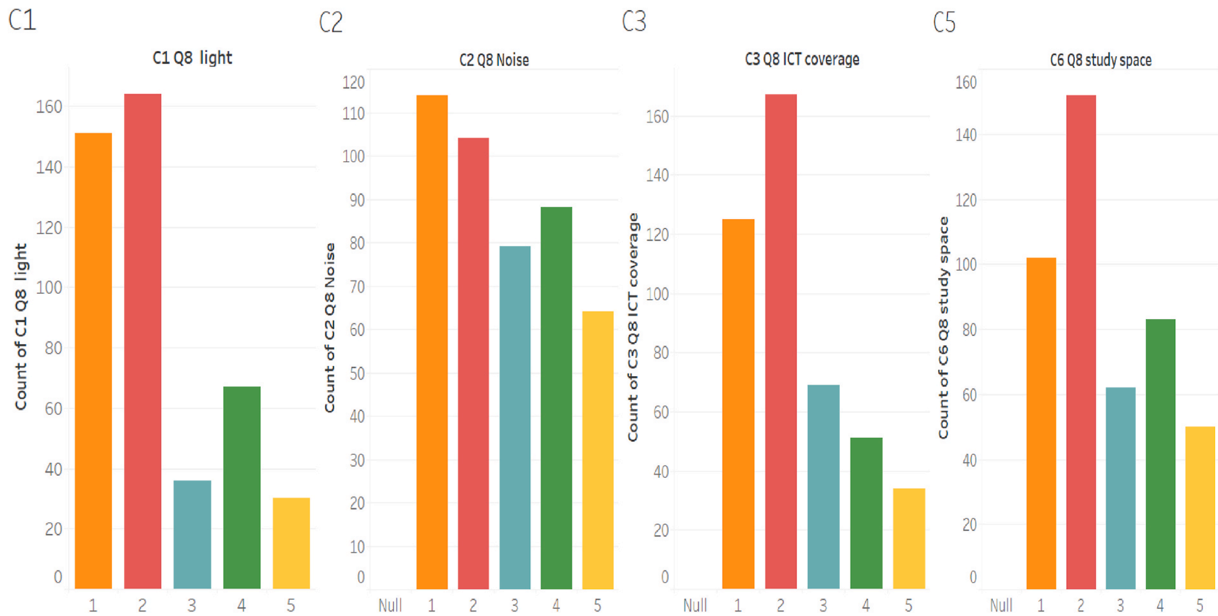

Fig. 7. 5-Point *Likert scale* assessment of comfort variables (n = 490 responses).

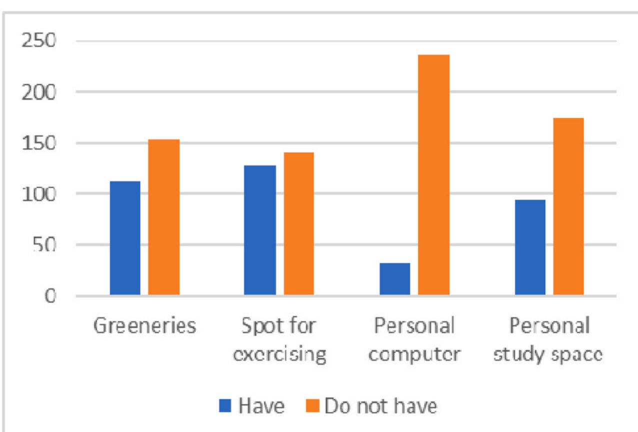

Fig. 8. The number of students dissatisfied with remote education concerning the presence of different residential facilities.

the measures such as Cronbach's Alpha (CA), Average Variance Extracted (AVE), Dillon-Goldstein's rho (rho_A), and Composite Reliability (CR) and latent variable scores (unstandardized outer weights between latent and manifested variables) were assessed. CA, CR, and rho_A represent the internal consistency measures of each latent variable. However, CR is claimed to be more accurate due to considering outer loading values [65]. The minimum acceptance criteria are 0.7 for both CA and CR. AVE validates the convergency of each latent variable, with a minimum acceptable value of 0.5. According to the results provided in Table 3, all the values meet the criteria of unidimensionality.

According to model assessment results summarized in Table 3, all SEM factors are reliable and valid, meaning that the proposed model can be used for further analysis (e.g., estimation of the relationships between the proposed factors and variables). In Table 3, the BE, SS, and AP factors are among the most reliable factors with their AVE, CR, Alpha, and Rho scores (over 80%). These results prove that the initial choice of the number of manifested variables was suitable. The inclusion of other variables to the factors may not only change (reduce) the reliability of the model but may also increase the cost of implementation.

Discriminant validity demonstrates the observed individuality of the developed model's measures of constructs [67]. Thus, establishing the validity of constructs' discriminants, the model hypotheses can be

Table 3
Outer model results and construct reliability and validity (Acceptance criteria: CA >0.7, AVE >0.5, rho_A >0.7 and CR > 0.7).

Latent variable	Manifest variable	Outer weights	Outer loadings	Mean	Standard deviation	Cronbach's Alpha	rho_A	CR	AVE	Latent variable scores (unstandardized)
Comfort (C)	C1	0.312	0.737	2.204	1.244	0.759	0.778	0.837	0.509	2.359
	C2	0.276	0.710	2.727	1.399					
	C3	0.234	0.690	2.304	1.202					
	C4	0.217	0.609	1.987	1.122					
	C5	0.347	0.808	2.585	1.306					
Health and safety (H&S)	HS1	0.267	0.593	2.038	1.046	0.748	0.755	0.835	0.506	2.312
	HS2	0.280	0.623	2.981	1.333					
	HS3	0.317	0.826	2.258	1.175					
	HS4	0.271	0.793	2.308	1.136					
	HS5	0.274	0.693	2.118	1.158					
Built environment (BE)	BE1	0.475	0.853	2.098	1.123	0.740	0.788	0.883	0.790	2.377
	BE2	0.644	0.923	2.672	1.285					
Academic performance (AP)	AP1	0.564	0.922	3.651	1.280	0.807	0.810	0.912	0.838	3.554
	AP2	0.528	0.910	3.456	1.282					
Student satisfaction (SS)	SS1	0.542	0.942	3.397	1.335	0.867	0.868	0.938	0.883	3.446
	SS2	0.522	0.937	3.491	1.235					

claimed statistically proven to be accurate. Table 4 shows the square root of the shared variance (diagonal values) and constructs' correlations (off-diagonal values). It suggests that all five constructs empirically differ from each other, showing that the model is validated.

A multigroup analysis was performed in order to establish the significant differences between specific data groups [68] that will ensure that group variances in model estimations outcome not due to different meanings of the latent variables and measurement scale [69]. For that, the measurement invariance in composite models procedure is used. In SmartPLS 3.0, Henseler's bootstrap-based MGA test was chosen for that, as we have only two groups to compare (CA and NE), and due to its solid result benefits among other parameter tests. This test is an outcome of the probability rate of a one-tailed trial by contrasting bootstrap approximations of the two groups [68]. Henseler's test is significant at 5% or 95% level; therefore, the permutation results will be checked for that.

As a first step, configural invariance was established, which means utilization of equal indicators in the datasets, same treatment of data, and similar PLS algorithm settings. As a next step, partial variance measurement was analyzed. Table 5 shows the results of this test. It is seen that significant differences for AP, BE, C, and SS are validated at a 5% level. In contrast, HS is validated at a 10% level only, which falls out of Henseler's test significance probability level. The third step – full variance measurement was also conducted (see Table 6). It was found that AP, BE, and C latent variables are validated for full variance measurement. However, HS and SS are not validated by this test, as their mean (original difference) values fall out of the interval of 2.5% and 97.5% boundaries. Moreover, Permutation p-values are less than 0.05 for HS and SS. Therefore, it can be concluded that only partial measurement variance is supported for our model (see Table 6).

Table 5
Partial variance measurement test results.

	Original Correlation	Correlation Permutation Mean	5.0%	Permutation p-Values
Academic Performance	1.000	1.000	0.999	0.331
Built Environment	0.999	0.999	0.998	0.185
Comfort	0.997	0.995	0.986	0.596
Health and Safety	0.989	0.996	0.990	0.038
Student Satisfaction	1.000	1.000	1.000	0.148

3.3. Implications of SEM model

The primary objective of the present research was to identify how the built environment facilities (such as comfort, health, and safety) impact students' satisfaction and academic performance during their remote education process in the recent coronavirus pandemic. This was assessed through the impact of the built environment's health and safety, and comfort constructs on academic performance and satisfaction constructs. The developed SmartPLS model that represents the proposed structural model (Fig. 2) has already been presented in Fig. 4. As this model's reliability and validity have been previously established for the present study, it is possible to go further in the model analysis. The path values (β) corresponding to the stated research hypotheses are summarized in Table 7. The *t*-statistic measures how many standard errors the coefficient is away from zero. Generally, any *t*-value greater than +2 or less than −2 is acceptable. The higher the *t*-value, the greater is the confidence in the coefficient as a predictor. Low *t*-values are indications of low reliability of the predictive power of that coefficient. At the same time, hypothesis confirmation is generally done by calculating a P-value for each route coefficient [70]. The smaller the P-value, the more substantial the evidence that one should reject the null hypothesis. Thus, P-values, provided in Table 7, are less than 0.000 for all the designed hypotheses, which means that they are statistically supported.

Hypotheses 1 and 2 are described by the impact of "Health and Safety" and "Comfort" to the "Built Environment," correspondingly. The path values are moderate and quite similar (β values are 0.381 and 0.382, respectively). It proves that residential health, safety, and comfort considerations are significant for the occupants in perceiving their homes ready to facilitate remote education. Moreover, such indicators as humidity (HS4), quality of indoor air (HS3), and comfortable study space (C5) are considered the most significant, as their path values (outer loading scores) are around 0.8. Nevertheless, it is also almost as important for students to have comfortable online studying amenities, such as availability of light (C1, β = 0.737) and satisfactory noise levels (C2, β = 0.710).

The other hypotheses – H3 and H4 – suggest that the built environment affects student satisfaction and academic performance during their remote study at home. Generally, the "student satisfaction" construct has a reasonably strong R^2 value of 0.681. The direct effect of the built environment on student satisfaction is much lower (0.249) compared to the effect of the built environment on satisfaction through academic performance (0.683). In turn, the built environment's impact on academic performance is moderate (0.445), while the R^2 value of academic performance is relatively low (0.198).

3.4. SEM behavior by living regions

The SEM represented in Fig. 9 shows the general view of the obtained responses towards the satisfaction with remote education in the built environment. The relationships between manifest and latent variables are represented by outer weights (Table 3). It is interesting to explore whether the SEM behavior would demonstrate changes by the regions: Central Asia (mainly represented by responses from Kazakhstani students) and Northern Europe (mainly represented by responses from Norwegian students). Delving further, as most respondents were from urban areas, the model in Fig. 4 is supposed to be more oriented towards the opinions of urban respondents. Therefore, it was also interesting to run the SEM analyses for urban, suburban, rural, and highly rural responses separately for each region to observe whether any alterations would occur in the values. Hence, the following SEM analyses are carried out using sub-datasets: (1) for Central Asia and Northern Europe regions; and (2) for urban and non-urban areas, which includes responses collected from respondents of suburban, rural, and highly rural areas. Table 8 sums up the path values of all the SEM models as mentioned above.

Some slight differences are noted in the SEM analysis for Central Asia and Northern Europe regions. For the students residing in Central Asia, health and residential safety facilities are more important features of the

Table 4
Discriminant validity of the constructs.

	Built Environment	Comfort	Health and Safety	Academic Performance	Student Satisfaction
Built Environment	0.889				
Comfort	0.641	0.714			
Health and Safety	0.641	0.680	0.712		
Academic performance	0.445	0.349	0.356	0.916	
Student Satisfaction	0.554	0.477	0.462	0.795	0.900

Table 6
Full variance measurement test results.

	Mean - Original Difference (CA - NE)	Mean - Permutation Mean Difference (CA - NE)	2.5%	97.5%	Permutation p-Values
Academic Performance	0.167	−0.003	−0.222	0.226	0.145
Built Environment	0.106	0.002	−0.234	0.222	0.385
Comfort	−0.106	0.001	−0.227	0.227	0.348
Health and Safety	0.303	0.006	−0.235	0.226	0.006
Student Satisfaction	0.287	−0.003	−0.227	0.227	0.016

Table 7
Hypothesis test results.

Hypothesis	Path	Original Sample	Sample Mean	Standard Deviation	T Statistic	P Value	Comment
H1	Health and Safety - > Built environment	0.381	0.378	0.1	3.794	0.000	Supported
H2	Comfort - > Built environment	0.382	0.389	0.099	3.869	0.000	Supported
H3	Built environment - > Student satisfaction	0.249	0.251	0.063	3.955	0.000	Supported
H4	Built environment - > Academic performance	0.445	0.448	0.082	5.428	0.000	Supported

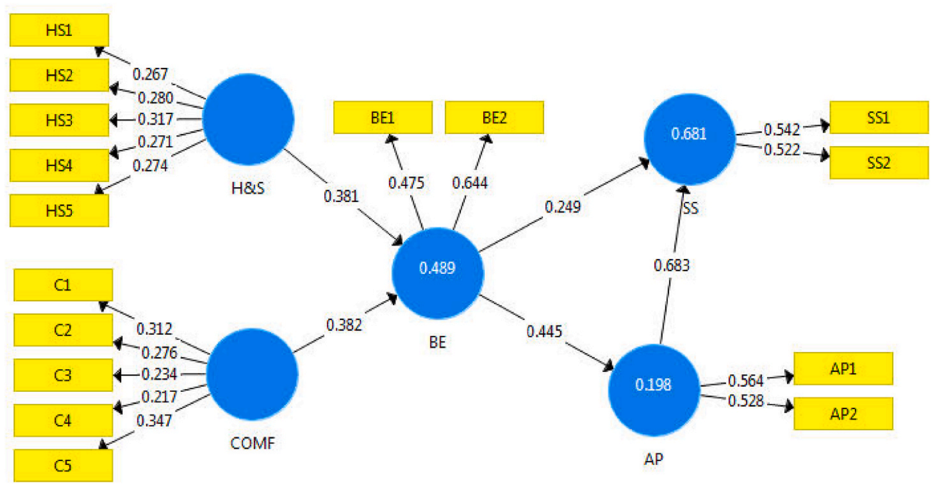

Fig. 9. Developed structural equation model in SmartPLS including Path coefficients between the latent constructs, the outer model weights, and, inside the circles, R^2 values.

Table 8
Hypothesis test results by regions and areas.

Path values (B) between			Central Asia region (355 responses)	Northern Europe region (95 responses)	Urban area (386 responses)	Non-urban area (138 responses)	Total (490 responses)
HS	BE		0.412	0.264	0.433	0.194	0.381
C	BE		0.365	0.515	0.325	0.601	0.382
	BE	SS	0.247	0.255	0.255	0.224	0.249
	BE	AP	0.436	0.554	0.430	0.492	0.445
	AP	SS	0.693	0.672	0.667	0.739	0.683

built environment (β = 0.412) than for respondents from Northern Europe (β = 0.264). Thus, comfort features are more significant (β = 0.515) to provide better-built environment conditions during the remote education process for residents of Northern Europe. Nevertheless, the effect of the Built Environment on Student Satisfaction is very similar for both regions – ranging from 0.247 to 0.255. In both areas, Built Environment has a much stronger effect on Student Satisfaction regarding its influence on Academic Performance, with B values ranging from 0.672 (for Northern Europe) to 0.693 (for Central Asia).

Talking about the SEM models separated by living areas, there are also some differences. In terms of the effect on the built environment, Health and Safety parameters are of higher importance for urban citizens' comfortable remote education process (0.433), while for non-urban residents, the Comfort features of the built environment are more significant (0.601). This finding can be linked to the fact that in non-urban areas, the internet connection (one of the indicators of the Comfort category) is weaker compared to urban areas, which, therefore, increases comfort's importance on student satisfaction. Rural areas have reported more problems with coverage and connectivity quality of communications technology (26% in rural and 45% in highly rural areas experience failing internet or electricity services more than once a week). In addition, rural citizens generally feel safer being surrounded by more green spaces [71]. They also have less exposure to crowded spaces (e.g., in public transport, elevators etc.) than urban citizens, while the prevailing number of single-family houses rather than residential complexes can make them generally feel safer during pandemics. The effect of the Built Environment on Student Satisfaction is more significant for residents of non-urban areas – 0.492 compared to urban residents – 0.430. In turn, the effect of Built Environment on Student Satisfaction is much more substantial through the Academic Performance indicator for all living areas – 0.667 and 0.739 for urban and non-urban respondents, respectively.

4. Conclusion

The present work aimed to explore and assess the effect of the residential built environment on the remote education's satisfaction and performance during the COVID-19 pandemic. It has been delimited by two regions: Central Asia (Kazakhstan) and Northern Europe (Norway). We measured the direct influence of the built environment readiness on improving the student satisfaction for remote education and the indirect influence through the student learning performance.

An analysis of the survey results ($n = 490$) showed that, based on the first regression model where students satisfaction is estimated by the built environment and academic performance, the built environment has relatively a low direct effect ($\beta = 0.249$) on student satisfaction with remote education. It was also found that academic performance has a substantial direct impact ($\beta = 0.683$) on student satisfaction. The model's explanatory power is found quite high ($R^2 = 0.681$), meaning that build environment and academic performance together are good estimators of the variance in student satisfaction. The results connected to the second model that analyses the relationship between build environment and academic performance suggest that built environment has a significant effect ($\beta = 0.445$) on academic performance. However, the model can explain only 19.8% of the variability in the dependent variable (i.e., academic performance). In summary, based on the results, the built environment factors have a significant influence on distance education performance (satisfaction and academic performance). However, according to the obtained R^2 values, it suggests other constructs be considered for more accurate prediction (e.g., campus life, group works, easy-to-get feedback, resource accessibility, and socioeconomic status).

The present study has confirmed that the proposed Structural Equation Model can explain the direct influence of the health (temperature, air quality, humidity, mental health) and safety (virus propagation), and as well as the comfort (space, noise, ICT, technical resources, light) on improving built environment behavior. Student satisfaction with remote education and academic performance depends on the built environment facilities, such as health, safety, and comfort. One of the general trends – the effect of the built environment on student satisfaction through academic performance is stronger than the sole influence of built environment on student satisfaction. An analysis by living regions (Central Asia and Northern Europe) showed that Central Asian students tend to ascribe more value to health and safety facilities at home, whereas Northern European students give more importance to comfort in its impact on remote education. Non-urban occupants are more interested in providing comfort facilities (e.g., improving communication technologies, adequate levels of light and noise, and comfortable study space). In contrast, city residents give more attention to health and safety issues (e.g., safety from virus propagation, access to greeneries, indoor air quality, and comfortable humidity and temperature). Separating the analysis "by countries" and "by living areas" helped better understand specific regions' behavior. These findings suggest that residential housing facilities should be improved differently and depending on the living area. Moreover, the effect of the built environment on academic performance has been empirically proven to bring increased student satisfaction rather than the sole impact of the built environment on satisfaction with remote education.

Decision takers are suggested to focus on developing digital equity for different living areas for more robust educational processes during pandemics, while researchers could further develop residences that would be sustainable to pandemics. The present work contributed to the literature in terms of residential facilities' development, especially when considering better equipment with communications technologies for rural areas. The main limitations of the present research include its geographical coverage (mainly limited to Kazakhstan and Norway), and the consideration of the effects of selected factors – built environment and academic performance – on student satisfaction. Therefore, in future works, we recommend considering social factors which might substantially impact students' satisfaction from the remote education process. We also recommend considering the effect of the subject studied, as majors of students might have an additional impact on their satisfaction with remote education.

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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.

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