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Perceived productivity in open-plan design library: Exploring students' behaviors and perceptions

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In higher education, libraries are facing drastic spatial changes, transforming areas traditionally used for housing books to spaces for interaction and shifting from individual to team-based learning. This study (a) identifies space uses; (b) examines the environmental satisfaction, support for productivity, and perceived productivity depending on space; and (c) tests their relationships. The results of 66 survey responses suggest that students still come to the library for individual study, and students in quiet zones show high environmental satisfaction. Environmental satisfaction is indirectly associated with creativity, while environmental support with acoustic comfort is directly related to concentration.

Introduction

One of the main functions of libraries is providing information and references through physical books and materials. Libraries in higher education, however, have faced momentous changes in their history. Based on technological advancement, an increasing number of academic libraries have shifted their physical materials and services online (Gardner & Eng, 2005; Hawkins, 2019). These changes offer an opportunity for spaces traditionally used for housing books to be utilized in different ways (Bryant et al., 2009; Yoo-Lee et al., 2013), for example, as areas supporting students' needs, including common spaces, meeting rooms, and spaces for formal and informal learning. Libraries have also made design changes, including expanding study areas, breaking up traditional library concepts, and providing electronic resources and a technology-based, learning environment, as well increasing commons spaces and providing learning services from staff (Xu & Yang, 2018).

Although there are fewer physical books and references in modern libraries in higher education, many college students still seek out space in libraries for studying (Applegate, 2009; Kim, 2017). The users are represented by members of generation Z, and they are typically connected to technology, work independently, and do both individual and group work (Hope, 2016). Libraries are designed for individual study as well as social activities, including working on group projects (Waxman et al., 2007). Group work is one of the new activities observed in the libraries, as there has been a trend shifting from individual learning to team-based learning in higher education (Hamilton, 2009). This new learning paradigm emphasizes sharing and discovering knowledge through discussion with others and requires a space that supports collaboration and communication in addition to individual study.

The new concept of learning space is represented by learning commons. A learning commons refers to a space for knowledge creation through collaboration and social interaction with advanced technologies (Bennett, 2008). Undergraduate students prefer to study and socialize simultaneously and to have unplanned meetings and social gatherings (Bryant et al., 2009). As students make use of libraries for various purposes—including as a place for study, seeking information, contemplation, and socializing (Kim, 2017)—libraries themselves should provide spaces to support such activities. Beckers et al. (2015) have suggested a theoretical model explaining four types of places within higher education for a new way of learning, depending on the level of social interaction and self-regulation in learning: (a) classroom settings, (b) informal learning settings, (c) collaboration settings, and (d) individual study settings. Informal learning settings can include cafés, social spaces, and information commons (Gayton, 2008; Lippincott, 2004).

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Space and behavior in academic libraries

Activities in a higher education library are similar to knowledge creation activities in the workplace (Townley, 2001). Knowledge creation requires a process of socialization, externalization, combination, and internalization to exchange and produce knowledge (Nonaka, 1994). Students also need socializing, learning, collaborating, and focusing activities for knowledge creation processes (Lee & Schottenfeld, 2014); these activities include both collaboration and individual work. For group use, furniture configurations can foster student engagement by encouraging serendipitous interactions. Such spaces also have to provide an environment for individual use to ensure concentration without visual and acoustic disruption. Spatial needs are different for the group and individual uses, and libraries should provide appropriate spaces for different uses. For group use, acoustic and thermal comfort are important factors for a group conducting learning activities versus socializing, and there are generally no significant differences in the importance of lighting, indoor air, amount of space, layout, and clean and healthy spaces for individual and group use (Lee, 2014).

Many studies have concluded that there are different spatial needs and outcomes for office environments depending on activities. For example, workers' productivity increased when they perceived that the workplace was appropriate for their activities (Hoendervanger et al., 2019). People working on individual high-complexity tasks preferred private offices, while people working on individual low-complexity tasks perceived that open-plan offices suited their work (Hoendervanger et al., 2019). Although workers considered quiet working one of the most important activities, an open-plan workplace did not support quiet working as much as workers expected (Chacon Vega et al., 2020). There are also space needs for different activities with appropriate layouts and acoustic and visual privacy (Chacon Vega et al., 2020). Workers showed different levels of satisfaction with noise depending on their work activity (Kang et al., 2017). People who used more than one workplace location—depending on activity—reported higher productivity in offices (Arundell et al., 2018; Haapakangas et al., 2018).

However, there has been a lack of research regarding space settings in higher education facilities. Studies about academic libraries have mostly focused on student behavior and perception of modern libraries and failed to link these aspects to student library outcomes, such as satisfaction and productivity (Applegate, 2009; Bryant et al., 2009; Kim, 2016, 2017; Yoo-Lee et al., 2013). As many universities have transformed and plan to continue transforming their spaces for physical books into spaces with various functions (Xu & Yang, 2018), it is important to know how such settings are associated with student productivity.

Environmental components and their impact on student productivity in an open-plan design

Bookshelves storing physical materials used to work as partitions to separate spaces, but many recently built or renovated academic libraries have reduced or replaced bookshelves with open-plan spaces for users (Beatty, 2016). Although repurposing such book shelving areas to open-plan spaces can facilitate informal learning and collaboration between students (Beatty, 2016), the limitations of open-plan settings should be considered from the aspect of satisfactory indoor environmental quality (IEQ) (Hongisto et al., 2016; Kaarlela-Tuomaala et al., 2009; Kang et al., 2017).

IEQ and spatial layouts in open-plan spaces are associated with user productivity (Agha-Hossein et al., 2013). The review paper by Al Horr et al. in 2016 has indicated that IEQ factors, including *air quality, thermal comfort, lighting,* and *noise*, influence occupant productivity. First, the *indoor air quality* (IAQ) is examined by the level of air contaminants and humidity (Al Horr et al., 2016). People perceive IAQ differently depending on the level of CO_2 (Varjo et al., 2015). The perceived IAQ can then be associated with productivity (Wargocki et al., 2000). Second, *thermal comfort*, measured objectively through temperature, is an important component in office environments, as it critically affects overall environmental satisfaction (Huang et al., 2012; Kang et al., 2017). Providing comfortable thermal conditions for every occupant is difficult, as thermal comfort is affected by various factors such as gender, age, and workstation location (Choi et al., 2012). Third, providing an adequate amount of *lighting* is important in work environments. Natural light is widely preferred to artificial light in that it provides better visual comfort (Lee et al., 2013) and positive mood (Kaida et al., 2007). However, regardless of preference, artificial light is necessary to provide illumination for the entire building when natural lighting is unavailable or inadequate. The required illuminance levels are also different depending on task: paper-based work requires higher than 500 lux, while computer-based work requires no more than 300 lux (Choi et al., 2012). Lastly, occupants perceive undesirable sound as *noise* (Huang et al., 2012); poor acoustic environments increase distraction, disrupt concentration, and reduce privacy, especially in open-plan offices, which decreases work productivity significantly (Kaarlela-Tuomaala et al., 2009). These ambient environmental components—IAQ, thermal comfort, lighting, and noise—have a significantly negative effect on productivity when the environment does not meet acceptable quality levels (Al Horr et al., 2016; Lamb & Kwok, 2016).

Spatial layout—which includes furniture type and configuration, the distance between others, view to the outside, and resources—is a critical factor that affects productivity (Brunia et al., 2016). Students have preferences for *furniture type and configuration* depending on their uses in a library (DeClercq & Cranz, 2014). Students prefer cozy and soft padded furniture for reading, tables with proper lighting for complex tasks, and carrel desks for studying (DeClercq & Cranz, 2014). *Distance to others* is related to multiple factors in open-plan offices. Close distances can increase distraction and noise and thus decrease productivity (Haapakangas et al., 2017), while proximity to others can also increase the frequency of communication with one another (Allen, 1977), which can be desirable for certain activities. *View to outside*, especially with natural components, is positively associated with well-being, restoration, and turnover intention (Kaplan, 1995; van Esch et al., 2019). Lastly, a modern library provides *resources*—such as outlets, whiteboards, and a Wi-Fi connection—to support student learning activities (Haug, 2008; Kim, 2016). Providing appropriate resources for students' needs can enhance student productivity.

Previous studies on workplace occupant productivity have mainly focused on the direct relationship between environmental satisfaction and perceived productivity. However, some studies have considered environmental support for productivity. Hua et al. (2011) examined the relationship between workplace spatial settings and environmental support for collaboration and found that a shorter distance from workstation to meeting space, shared service area, and kitchen supported occupant collaboration. De Been and Beijer (2014) suggested that people perceived the support for productivity differently depending on their office type; the support for productivity was higher in room offices than in combination or flex office. These studies argued that the office layout could be the predictor of productivity support, but did not include environmental components in the test. Prior studies have not tested the relationship between perceived support and productivity or examined the direct link between environmental factors and support. To understand how physical environments, productivity supports, and productivity are related, further studies are required to build upon the results from the previous studies.

Research objectives and hypotheses

Given the changes in libraries in higher education and the importance of their built environments, it is important to understand whether or not modern academic libraries meet the needs of users (in this case, college students) by observing the patterns of space use and examining the environmental support for enhanced productivity. This study therefore identified users' behavior patterns in a modern library; assessed users perceived environmental satisfaction, support for productivity, and productivity depending on space type; and examined the relationship between the built environment, support for productivity, and perceived productivity of library users. We therefore developed the following hypotheses:

H1: Students prefer different types of spaces, depending on intended space use (i.e., alone, in a group, and alone but together), in a library.

H2: Students perceive environmental satisfaction, support for productivity, and productivity differently depending on space type (i.e., ideation space and quiet zone).

H3: Students' environmental satisfaction levels are positively associated with their perceived support for productivity and productivity in a library.

Methods

Study site

The Dorothy M. Crosland Tower is a library and learning commons building constructed in 1968 and fully renovated in 2018. It is located in the center of Georgia Tech's Atlanta campus. The building was renovated to support interdisciplinary collaboration, innovative learning, and community building (*Reimagine the Georgia Tech Library*, 2019). It has an area of 126,823 gross square feet (GSF) on nine stories, consisting of a basement, ground, and 1st to 7th floors. The renovated library has limited space for physical books: an archive space on the first floor and storage space on the ground floor. The spaces for students in this building are mainly designed as open-plan layouts without carrels, including both quiet and collaboration spaces. In addition to such spaces, there are multimedia rooms, reservable meeting rooms, and one classroom, which is not for regular classes, but for workshops or special programs provided by the library. A part of the third floor and the entire fourth floor are for library staff. The open-plan study area consists of spaces named "ideation space" (Figure 1-1) for collaboration, which allows conversation, on the second floor and "quiet zone" (Figure 1-2) on the sixth and seventh floors, depending on the purpose of each space. The ideation area (second floor) provides counter-height desks (35–39 inches) with stools, tables with benches, whiteboards, and multimedia tools, such as wide displays to share a personal laptop screen to foster in-person communication. The quiet zones (sixth and seventh floors) contain writing desks for six to eight people, round tables for four people, tables with high-back sofas for four people, single lounge chairs, sofas for four to six with and without a table, and do not allow discussion or conversation.

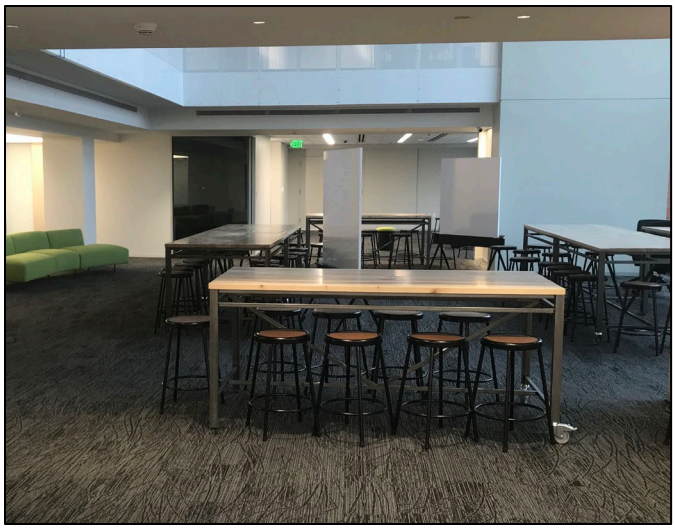

Figure 1-1. Example photo of an ideation space

Figure 1-2. Example photo of a quiet zone

Survey

The survey assessed five main elements: (a) behaviors in the library, (b) satisfaction with the indoor environment, (C) perceived productivity, (d) perceived environmental support, and (e) demographic questions. First, the survey asked about preferred spaces on campus (depending behaviors), the reasons for visiting the library, the type of space use, and respondents' behavior in the subject library. The types of space use included (a) solitary, (b) work as a group, and (c) using the space alone but together, which means students come to a space together, but work on their own tasks. Respondents were also asked to choose their activities from among studying, group projects, resting, and others. Second, the survey items related to indoor environments asked respondents' satisfaction with ambient environments and spatial features. The ambient environment included lighting, thermal comfort, noise, and IAQ. Spatial features included furniture configuration and type, distance to others, view to the outside, and activity support materials, such as whiteboards, power outlets, and stable Internet service. These items asked respondents to rate their satisfaction levels using a 5-point Likert scale (from 1 = *strongly dissatisfied* to 5 = *strongly satisfied*). The third part evaluated perceived productivity. The productivity of library users was evaluated by their concentration, quality of work, quantity of work, and creativity (Sundstrom et al., 1994). The productivity related to a learning commons was also queried in terms of collaboration, community, and creativity (Schmidt & Kaufman, 2007). The questions used a 5-point Likert scale (1 = *very low* to 5 = *very high*). The next part asked the level of environmental support for communication, collaboration, creativity, and concentration with a 5-point Likert scale from 1 = *very low* to 5 = *very high*. The last part consisted of demographic questions, including gender, age, position, residence (living in a dorm), ethnicity, and years in the school. All statistical analyses were performed using R studio.

Survey procedure and sample

The authors conducted a survey about student behavior and perception of the new library settings. The survey was administered via an online survey platform, Qualtrics. Participants were asked to answer the questions by scanning a QR code on a survey flyer linked to the online survey. The sheets were located on tables in open-space study areas on the second, sixth, and seventh floors, so students could participate while they were using the library. Data were collected from Monday, October 21, 2019, to Friday, October 25, 2019. A total of 66 responses were collected (Table 1).

Results

Student behavior patterns in learning commons

As the library does not provide physical books, its open-plan spaces are not unique compared to other study spaces on campus. Students have many available study space options, such as classrooms, common areas, dining halls, or cafés on campus. This study investigated users' preferences for spaces on campus that have similar properties to those in the library (Table 2). The students chose the space to use depending on their activities. When they used space on campus by themselves, the students preferred to use libraries (73.73%), followed by common areas (7.58%). When

Table 1. Respondent Characteristics (n=66)			
Demographic	**%**	**Demographic**	**%**
Gender		***Ethnicity***	
Male	50.00	White	39.39
Female	50.00	Black or African American	9.09
Age		Hispanic or Latino	6.06
18–24	87.88	Asian/ Pacific Islander	43.94
25–29	10.61	Other	1.52
30–34	1.52	*Years in the school*	
Position		Less than 1 year	54.55
Undergraduate student	74.24	1 ~ 2 years	15.15
Graduate student	25.76	3 ~ 4 years	19.70
Living in a dorm	50.00	5 years or more	10.61

Table 2. Preferred Spaces Depending on Use (n=66)				
	Alone	**In a group**	**Alone, but together**	**Total**
Library	48 (73.73%)	24 (36.36%)	12 (18.18%)	84 (42.42%)
Classroom	0 (0.00%)	0 (0.00%)	3 (4.55%)	3 (1.52%)
Commons area	5 (7.58%)	24 (36.36%)	32 (48.48%)	61 (30.81%)
Dining hall	1 (1.52%)	5 (7.58%)	1 (1.52%)	7 (3.54%)
Café on campus	2 (3.03%)	4 (6.06%)	2 (3.03%)	8 (4.04%)
Department building for student major	3 (4.55%)	6 (9.09%)	11 (16.67%)	20 (10.10%)
Office	1 (1.52%)	1 (1.52%)	0 (0.00%)	2 (1.01%)
Dormitory	2 (3.03%)	2 (3.03%)	3 (4.55%)	7 (3.54%)
Others	4 (6.06%)	0 (0.00%)	2 (3.03%)	6 (3.03%)
Total	66 (100%)	66 (100%)	66 (100%)	198 (100%)

using a space in a group, students preferred either libraries (36.36%) or common areas (36.36%), followed by department buildings (9.09%), dining halls (7.58%), and cafés (6.06%). Lastly, for use alone but together, students selected commons areas as the most preferred space, followed by libraries (18.18%) and department buildings (16.67%).

Students visited the library for different reasons (Table 3). However, as shown in Table 2, the reasons were mainly related to the supportive environment for individual study, as students mainly use the library when they study alone. Many students come to the library because of less distraction (68.18%), good IEQ (60.61%), and a study-friendly atmosphere (56.06%). However, fewer students answered studying with friends (18.18%) and safety and security (15.15%) as explanations.

In terms of activities, more than three-quarters of students (77.27%) visited the library to study, followed by miscellaneous work (9.09%), group projects (7.58%), and lounging/resting/eating (6.06%). Respondents were asked to choose all resources that they were using in the library, and more than half (54.55%) used multiple resources simultaneously. Most students (89.39%) used laptops, while about half (51.52%) used physical books and papers. They also used smartphones (36.36%) and tablets (9.09%). Only a small number (1.51%) used a whiteboard. Students chose space types depending on their use (Table 4). The result of a chi-square test showed that the relationship between space type and space use was significant ($\chi 2 = 15.19$, $df = 2$, $p < .05$). Most (38/48) students who used a space alone chose a quiet zone, while 7 out of 8 individual students used an ideation space with a group. Students who were alone but together used the quiet zone and ideation space equally. These results found that students chose the building and space depending on their use, which supports H1.

Environmental satisfaction and perceived productivity depending on the space type

An independent sample t-test was used to determine the difference in environmental satisfaction, support for productivity, and perceived productivity depending on space type—specifically, the ideation space and quiet zone. The results showed different outcomes depending on space type (Table 5). For environmental variables, students in the quiet zone reported significantly higher levels of satisfaction with natural light ($t(31.617)=2.552$), noise ($t(64)=2.703$), background noise ($t(64)=3.042$), IAQ ($t(64)=2.378$), furniture

Table 3. Reasons for using the library (multiple responses)			
Reason to come to library	**N of responses**	**% of responses**	**% of cases**
Less distraction	45	16.79	68.18
Good indoor environmental quality (e.g., temperature, noise, air quality)	40	14.93	60.61
Study-friendly atmosphere	37	13.81	56.06
Controllability of study environment	30	11.19	45.45
Spatial layout (e.g., furniture, sufficient space)	27	10.07	40.91
Resource (e.g., computers, outlets, Wi-Fi, printers)	23	8.58	34.85
Convenience location	22	8.21	33.33
Access to windows	22	8.21	33.33
Study with friend(s)	12	4.48	18.18
Safety and security	10	3.73	15.15
Total	**66**	**100%**	—

Table 4. Space Use and Building Location (n = 66)				
Variable		**Space use**		
		Alone	**In a group**	**Alone, but together**
Space type	Quiet zone	38 (79.17%)	1 (12.5%)	5 (50%)
	Ideation space	10 (20.83%)	7 (87.5%)	5 (50%)
Total		**48 (100%)**	**8 (100%)**	**10 (100%)**

type (t(64)=2.191), and view to the outside (t(64)=2.292) compared to those in the ideation space.

There were also significant differences in perceived environmental support and productivity between students in the ideation space and those in the quiet zone, and the results for support and productivity showed similar patterns. The students in the ideation space showed significantly higher environmental support for collaboration (t(60.518)=−3.252) and communication (t(60.248)=−2.816) and yielded significantly higher productivity for collaboration (t(64)=−2.550) and communication (t(64)=−3.575) than those in the quiet zone. In the quiet zone, on the other hand, students perceived a significantly higher level of environmental support for creativity (t(64)=2.228) and concentration (t(64)=3.006) compared to students in the ideation space. Students in the quiet space also reported a higher level of perceived productivity for creativity (t(64)=2.495), quality of work (t(64)=3.113), quantity of work (t(64)=2.551), and concentration (t(64)=3.442) than those in ideation spaces.

The result thus partially supported the second hypothesis: environmental satisfaction with natural light, noise, background noise, IAQ, furniture type, and view to the outside was perceived differently depending on space type (quiet space vs. ideation space), but the satisfaction with overall light, artificial light, temperature, furniture configuration, distance to others, and resources did not differ. H2 was supported in terms of differing support for productivity and perceived productivity depending on space type.

Relationship between environmental satisfaction and perceived productivity

Given that the two spaces had a different association with distinct productivity variables, a data set was created separated by space type—ideation space (n = 22) vs. quiet zone (n = 44)—for analysis. As the number of samples in the ideation spaces was too small to conduct statistical analysis, the analyses used the samples in the quiet zone only. Mediation analyses were performed to investigate the relationship between environmental satisfaction, environmental support, and perceived productivity.

The mediation analysis followed three steps. First, multiple regression analysis with the stepwise method was conducted with environmental satisfaction as the independent variable and each productivity variable as an outcome variable (Path C in figure 2) using the "MASS" package with R studio with the stepwise method. After determining the significant variables, another regression analysis was performed, adding the mediator variable of environmental support as a dependent variable (Path A in figure 2). Finally, if there was a significant relationship for environment satisfaction with support for productivity, multiple regressions were conducted with the environmental satisfaction variables as independent

Table 5. Independent Sample T-test for Environmental Satisfaction, Support for Productivity, and Perceived Productivity Depending on Spaces

Variable	Ideation space (n=44)		Quiet zone (n=22)		Independent sample t-test	df
	M	SD	M	SD		
Environment						
Overall light	4.136	0.774	4.341	0.939	0.882	64
Natural light	3.955	0.899	4.500	0.629	2.552*	31.617
Artificial light	3.682	0.646	3.977	0.927	1.338	64
Noise	3.409	0.908	4.114	1.039	2.703*	64
Background noise	3.364	0.953	4.023	0.762	3.042*	64
Temperature	3.772	0.752	3.909	0.910	0.606	64
Air quality	3.500	0.740	4.000	0.835	2.378*	64
Furniture configuration	3.773	0.973	3.977	1.067	0.755	64
Furniture type	3.091	1.192	3.795	1.250	2.191*	64
Distance to others	3.818	0.853	3.864	1.133	0.166	64
View to outside	4.181	0.795	4.590	0.622	2.292*	64
Resources	3.590	1.141	4.068	0.974	1.778	64
Environmental support						
Collaboration	3.273	0.827	2.409	1.317	-3.252*	60.518
Communication	3.136	0.834	2.386	1.316	-2.816*	60.248
Creativity	3.000	0.873	3.523	0.876	2.288*	64
Concentration	3.318	1.129	4.113	0.920	3.066*	64
Productivity						
Collaboration	2.909	0.971	2.182	1.147	-2.550*	64
Communication	3.091	0.868	2.091	1.158	-3.575*	64
Creativity	2.909	0.921	3.523	0.952	2.495*	64
Quality	3.364	0.727	4.023	0.849	3.113*	64
Quantity	3.272	0.767	3.818	0.843	2.551*	64
Concentration	3.272	0.939	4.159	1.077	3.442*	64

variables and the mediator variable on the dependent variable (Path B and C′ in figure 2).

The analyses used two of the six productivity variables—creativity and concentration—as dependent variables. Those two variables were reported higher in the quiet zones than in the ideation spaces. Collaboration and communication were not tested as dependent variables because they are not encouraged in the quiet zone. Lastly, the support for quantity and quality of work were not measured, so the model cannot be tested using those variables. The analyses resulted in two sets of three models based on Figure 2. All models satisfied linearity, homoscedasticity, independence, and normality assumptions for regression analysis.

For creativity (Table 6), the regression analysis with the stepwise method yielded a model that included overall lighting, furniture configuration, and furniture type variables ($F(3, 40) = 4.256$, $R^2 = .185$). Among the variables, Model 1 indicated that satisfaction with overall lighting was significantly associated with creativity level. Model 2 used the same independent variables as the first model, and the dependent variable was support for creativity ($F(3, 40) = 5.318$, $R^2 = .232$); the result showed that the overall lighting variable was statistically significant. The final model (Model 3) tested the mediation effect of support for creativity ($F(4, 39) = 9.774$, $R^2 = .449$). The support for the creativity variable was significantly related to the perceived level of creativity, while the effect of the overall lighting disappeared. The relationship between overall lighting and creativity was entirely through support for creativity and was not a direct relationship. In this case of creativity, the third hypothesis was partially supported: environmental satisfaction with overall lighting was positively associated with creativity, mediated by support for creativity.

In Table 7, the first regression analysis on concentration yielded a model that included overall lighting, artificial lighting, noise, background noise, air, and distance to others as independent variables ($F(6, 37) = 21.87$, $R^2 = .774$). However, the regression coefficient of artificial lighting was negative because of the partial correlation coefficient shown in Table 8. This result showed the reverse relationship between satisfaction with the artificial lighting and perceived concentration. Satisfaction with lighting in a

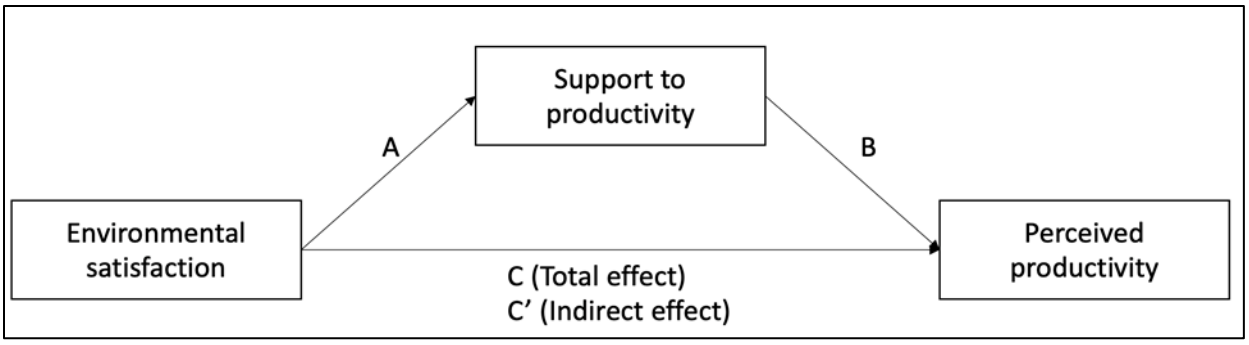

Figure 2. Model of environmental satisfaction, productivity support, and productivity

Table 6. The result of the mediation analysis: Creativity (n = 44)			
	Model 1	Model 2	Model 3
DV	Creativity	Support for creativity	Creativity
Independent variables			
Overall lighting	.415 (.152)*	.399 (.136)*	.154 (.138)
Furniture configuration	.349 (.181)	.255 (.162)	.183 (.153)
Furniture type	-.310 (.156)	-.098 (.139)	-.246 (.129)
Mediator variable			
Support for creativity	-	-	.654 (.146)*
R^2	.185	.232	.449
F (df)	4.256 (3, 40)*	5.318 (3, 40)*	9.774 (4, 39)*

The numbers in parentheses are standard errors.
* P<.05

positive relationship with concentration and task performance is rational, as found in other studies (Sleegers et al., 2013; Veitch et al., 2008), and the positive relationship between support for concentration and satisfaction with artificial lighting is also reasonable. The inverse relationship may arise from multicollinearity both between overall lighting and artificial lighting and between artificial lighting and noise. Although many studies have tested multicollinearity between IEQ stimuli (Kim & de Dear, 2012; Park et al., 2018), interaction effects between the IEQ factors were claimed (Huang et al., 2012; Tang et al., 2020). This study found that satisfaction with artificial lighting was associated with overall lighting, so, in this case, the artificial lighting variable was removed from the analysis.

After removing the variable satisfaction with artificial lighting, three models were generated to test the relationship between environmental satisfaction, support for concentration, and perceived concentration. Model 1 included overall lighting, noise, background noise, air, and distance to others as independent variables ($F(5, 38) = 21.63$, $R^2 = .706$). In this model, satisfaction with noise, air, and distance to others was positively associated with the dependent variable, concentration. Model 2 tested the relationships between the independent variables from the first model and support for concentration ($F(5, 38) = 13.25$, $R^2 = .588$); overall lighting was significantly related to the support for concentration. Model 3 tested the mediation effect and found that noise, distance to others, and support for concentration were significantly associated with the level of concentration ($F(6, 37) = 27.53$, $R^2 = .787$). In other words, the relationship between satisfaction with overall lighting and concentration was partially mediated by support for

Table 7. Result of Regression Analysis: Concentration (n=44)

Variable	Coefficient (std. error)
Independent variables	
Overall lighting	.203 (.119)
Artificial lighting	-.230 (.088)*
Noise	.325 (.104)*
Background noise	.211 (.114)
Air	.334 (.108)*
Distance to others	.143 (.085)
R^2	.744
F (df)	21.87(6, 37)*

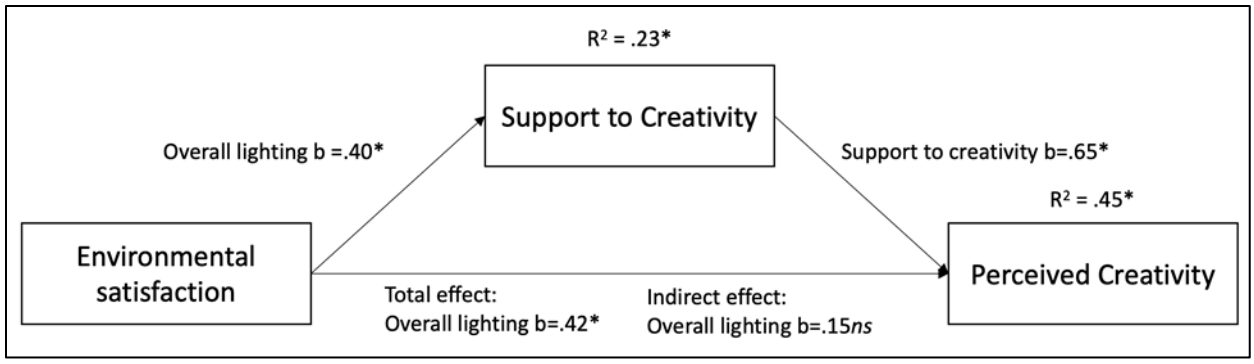

Figure 3. Relationship between environmental satisfaction and perceived creativity

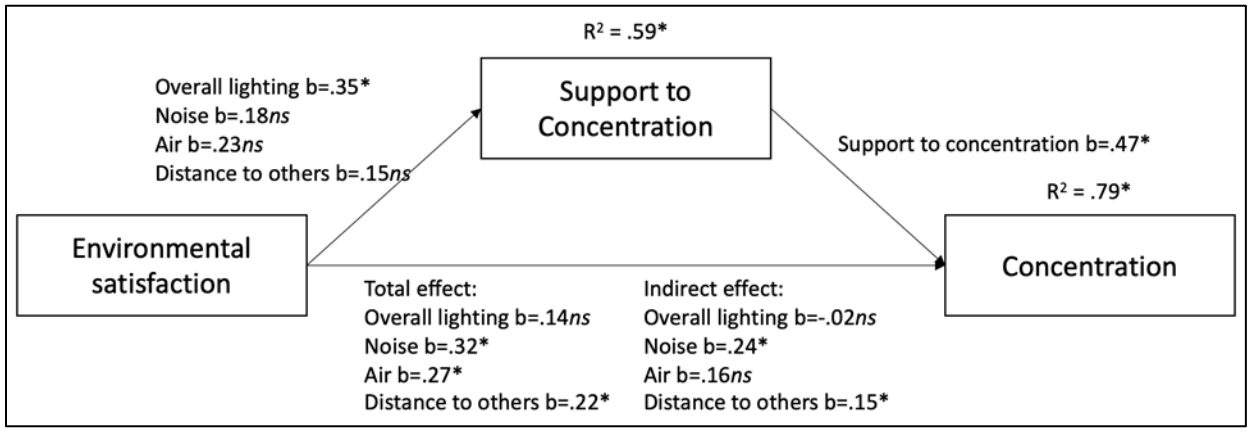

Figure 4. Relationship Between Environmental Satisfaction and Perceived Concentration

concentration. Noise and distance to others were directly related to concentration.

Discussion

This study examined the relationships between library use (individual, group, alone but together), use of resources, ambient environmental satisfaction, spatial satisfaction, perceived environmental support, and perceived productivity in a library building via a survey. The findings raise interesting points concerning new modes of library use and the indirect relationship between environmental satisfaction and productivity, which could be considered for future library renovation or design projects.

First, consistent with DeClercq and Cranz (2014), students no longer come to the library to search for references. However, many students still use the library for individual and group work. Most students in the subject library were alone, as students preferred to use the library for individual study rather than for group work. Although the intention of the library design was to enhance communication and collaboration with other students, only about 36% of students preferred using the library for working in a group; students were more likely to use other spaces such as common areas and department buildings for group work. For using alone but together, about half of the students preferred the common areas, followed by the library (18%). It is notable that the design intention of the library was as a learning-commons for collaboration, but students reported a different preference for library use than for other commons spaces.

In the past, libraries provided desktops with software programs and Internet access to students (Gardner & Eng, 2005; Lippincott, 2004). However, the trend is changing as libraries provide only a minimum number of desktops. Instead, students bring their laptops or other devices, depending on their needs. The proportion of using a laptop in a library increased up to about 90%, compared to 25% in 2008 (Applegate, 2009). The students in this study also used portable devices, such as a smartphone or tablet. As more and more students bring and use various technologies into the library, it is important to provide technology-friendly environments that include enough outlets, technology support services, and a stable Wi-Fi connection.

Interestingly, students' uses of space were consistent with the design intent of the separation between quiet and

Table 8. Correlation Coefficients for Environmental Satisfaction and Support for Concentration and Perceived Concentration (n=44)						
Variables	**Overall lighting**	**Artificial lighting**	**Noise**	**Background noise**	**Air**	**Distance to others**
Support to concentration						
Full correlation	0.708	-0.051	0.667	0.427	0.575	0.550
Partial correlation	0.424	-0.382	0.046	0.135	0.223	-0.082
Concentration						
Full correlation	0.676	0.031	0.744	0.515	0.623	0.633
Partial correlation	0.035	-0.161	0.389	0.201	0.300	0.275

Table 9. Results of Mediation Analysis: Concentration			
	Model 1	**Model 2**	**Model 3**
DV	**Concentration**	**Support for concentration**	**Concentration**
Independent variables			
Overall lighting	.139 (.125)	.345 (.145)*	-.022 (.114)
Noise	.320 (.112)*	.178 (.130)	.236 (.098)*
Background noise	.163 (.121)	.124 (.140)	.104 (.104)
Air	.269 (.113)*	.225 (.131)	.163 (.100)
Distance to others	.216 (.086)*	.134 (.100)	.153 (.075)*
Mediator variable			
Support for concentration	-	-	.469 (.119)*
R^2	.706	.588	.787
F (df)	21.63 (5, 38)*	13.25 (5, 38)*	27.53 (6, 37)*

The numbers in parentheses are standard errors.

* P<.05

collaboration spaces. Most students who stayed alone used the quiet zone, while students working in a group preferred the ideation space. This indicates that students tend to choose the space that fits their work, which empirically supports the theoretical model by Beckers et al. (2015) arguing the alignment of learning space with space uses. The separation of spaces with different uses can also improve the acoustic quality in a library (Xiao & Aletta, 2016), which is important because people perceive noise levels differently depending on the activity context: people who focus on individual work prefer a quiet environment. It is therefore important to define the various student activities in a library and provide appropriate spaces to support each activity.

Creativity is associated with the physical workplace and positive perception of the environment, so there is a possibility that poor workplace design could decrease occupant creativity (Samani et al., 2014). In this study, the perceived level of creativity was higher in the quiet zone than in the ideation space. Team creativity is affected by collaboration and communication, so providing an appropriate spatial arrangement to encourage these activities is important to enhance team creativity (Martens, 2011). Although the ideation space provided furniture for groups, satisfaction with the furniture configuration was lower than for the quiet zone, and furniture type was the variable that elicited the least satisfaction. The dissatisfaction with the environment was associated with the lower level of creativity in the ideation space. Individual creativity is not related to communication and collaboration, so the higher level of creativity in a quiet zone could be associated with higher environmental satisfaction, as the general environmental satisfaction level was higher in the quiet zone. Students reported that they were more creative or capable of doing creative work in the quiet zone because they had higher ambient environmental comfort.

Another notable result was that students perceived environmental support differently depending on which space zone they were using. Although all spaces were designed with an open-plan concept, students reported different levels of environmental supportiveness, noting a higher level of environmental support for creativity and concentration in the quiet zones and a higher level of productivity in creativity, quality of work, quantity of work, and concentration compared to the ideation spaces. In the ideation spaces, meanwhile, students reported a higher level of environmental support, as well as productivity in

collaboration and communication. For appropriate use of space, the purpose of the space needs to be specified so explicit zoning can lead students to use the spaces that meet their needs. Babapour Chafi and Rolfö (2019) found that explicit rules for space use, such as zone-specific speech or phone policies, would help users comply with the rules. Organizations with quiet and semi-quiet zones allowed users to avoid distractions more than those without or with ambiguous rules (Babapour Chafi & Rolfö, 2019). Open-plan offices often have noise problems (Hongisto et al., 2016). A study by Hoendervanger et al. (2019) reported that the perceived environmental fit and productivity of a high complexity task would be higher in private offices compared to open-plan offices. However, this study showed that, with explicit zoning, open-plan spaces could also provide a space with environmental support for concentration.

In the most prior studies, the relationship between environmental satisfaction and productivity was tested directly. In this study, the mediating effect of support for productivity was tested, and the results provide new insight into the relationship between environmental satisfaction and perceived productivity of creativity and concentration, which is associated with support for productivity. For creativity, satisfaction with overall lighting was associated with support for creativity but not directly related to perceived creativity. Providing an appropriate level of overall lighting for individual study makes students feel supported in the environment, so students choose the space based on this perceived support for productivity. For concentration, satisfaction with the overall lighting is related to support for concentration, but is not associated with concentration directly. Interestingly, satisfaction with noise and distance from others is directly related to support for concentration and not related to support for concentration. This suggests that a space can increase the perceived level of concentration by improving satisfaction with noise levels and distance to others. The distance should be close enough within a group to communicate effectively, but needs to be far enough to decrease the conversation noise for those outside the group. Further studies on environmental support for productivity are warranted.

As seen in the results, the environmental components are positively associated with students' perceived support for productivity in the library. These findings imply that the environment was more important to concentration than to creativity. For concentration, students demanded diverse elements of environmental satisfaction, including overall light, noise, and air. According to Nonaka's (1994) SECI model of knowledge dimensions, knowledge creation requires not only interaction between people for *socialization* and *combination* but also an individual learning process for *externalization* and *internalization*. Concentration is important for the individual learning phase of knowledge creation, but recent workplace studies have been more inclined to focus on collaboration. The outcomes of this study imply the importance of providing the proper environment for individual learning and concentration. Furthermore, providing separate spaces to support different study activities is required to promote various behaviors in the library effectively.

The relationship between environmental components and perceived productivity found in this study can guide space programming to determine which space should be provided with which specific environment. For example, a space with sound dampening material should be designated for concentration activities based on the result that satisfaction with noise is one of the significant factors to enhance concentration. Satisfaction with overall lighting and air is especially significant for designing a space for concentration, so students feel environmental support. Satisfaction with noise also makes it possible to improve a space's concentration level.

In summary, the findings of this study have significant practical implications. It is crucial to provide appropriate spaces and equipment to support different behaviors in university libraries. This result supports the idea that the concept of the Activity-Based Workplace (ABW), which aims to provide different spaces for various activities in an office, can be applied to a university library. Explicitly defined zoning would help students use a space for its intended purpose. It should be noted, however, that this study focuses on one academic library building. The results may not be generalizable to other buildings or contexts. The sample size was also limited. Modern academic libraries share similar spatial designs and main users (college students), so they may share similar characteristics in terms of learning and social activities. Each library transformation case should fully consider users' specific needs for each context.

Conclusion

This study suggests the importance of exploring student behavior and perceived productivity in academic libraries. Although they pursue the creation of a learning commons, libraries still have to provide a space and appropriate environment for individual focused work. Many students use libraries to study alone or in a group. These two activities are significantly different and require separate spaces to ensure productive performance. Students studying alone need a quieter, more comfortable space compared to people working as a group. Environmental satisfaction is associated with support for productivity, and at the same time, it is also indirectly associated with perceived productivity. This makes it possible to provide appropriate environments, including space programming and environmental quality.

Such appropriately designed spaces can enhance students' productivity in academic libraries. Compared to the importance of the environment in higher education libraries, there has been a lack of research in modern library trends and the relationship between the perceived built environments and student productivity. This paper provides evidence that the library should offer various types of spaces. Another strength of this study is that the indirect relationship between environmental satisfaction and productivity through support for productivity was found. As previous studies have tested only a direct association, further studies on indirect relationships should be explored further.

Future studies on various library spaces and behaviors are suggested based on this study because it used one case with a limited number of students. Future work should be extended to additional library cases to test and validate the results. Other space types could also be included, such as cafés, social spaces, and library meeting rooms.

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