Interface of Indoor and Outdoor Spaces in Buildings

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A Syntactic Comparison of Architectural Schools in Istanbul

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Abstract

Educational atmosphere in schools of architecture can be connected to interrelation of indoor/outdoor spaces as well as the environmental effects. No matter what the level of education is, the outdoor spaces are crucial for the student life; thus the school designers take this matter into serious consideration. Moreover, architectural school designs are also a critical issue for architectural students, as they set an example of application.

In most cases, architectural school designs somehow suffice the optimum settings for the requirements. However, there are numbers of school design choices, where the outcomes are solely defined by the pragmatic decisions; such as the two oldest state architectural schools of Istanbul, MSGSU and ITU, where large scaled institutional buildings were converted with concerns of spatial adequacy rather than a design strategy. This paper mainly focuses on the examination of the educational environs of these 150 years old buildings and their interface between indoor and outdoor spaces.

This research focuses on the comparison of the frequency of students' occupancy in the interfacing areas of the ground floors and the syntactic values of these spaces both in clear and rainy weather comparatively. The interfacing spaces are denoted as a courtyard for ITU, and a seaside terrace for

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MSGSU. The time dependant usage of the extension of thresholds; i.e. the interfacing spaces, in terms of halls, yard, lawn, courts, halls, corridors and such, are the syntactic experiment areas of the research. The time dependent occupancy of students and the punctuation for the determined frequency in indoor/outdoor spaces are the preliminary testable comparison between the schools. The research hypothesis assumes that the frequency of the space usage by the occupants is linked to the spatial configuration of the environment, in terms of designed milieu, location type, visual capacity and integration.

1. Introduction

Students' social behaviour at university buildings, their social interactions and their gathering areas are among the important issues of architectural programming and architectural design performance. These issues show many implications about the usage of interior spaces of university buildings and the characteristics of physical determinants, which play a part in social interaction in outdoor spaces (Ünlü et al. 2001).

Architectural legibility, spatial identity, orientation and way finding are among the main factors of cognitive mapping, perception and thus, socio-behavioural preference in a physical environment (Downs and Stea 1973, 8-26). Educational atmosphere in schools of architecture can be connected to interrelation of indoor/outdoor spaces as well as the environmental effects. No matter what the level of education is, the outdoor spaces are crucial for the student life; thus the school designers take this matter into serious consideration. Moreover, architectural school designs are also a critical issue for architectural students, as they set an example of application.

In most cases, architectural school designs somehow suffice the optimum settings for the requirements. However, there are numbers of school design choices, where the outcomes are solely defined by the pragmatic decisions; such as the two oldest state architectural schools of Istanbul, Mimar Sinan University of Fine Arts (MSGSU) and Istanbul Technical University (ITU), where large scaled institutional buildings were converted with concerns of spatial adequacy rather than a design strategy. This paper mainly focuses on the examination of the social environs of these 150 years old buildings and their interface between indoor and outdoor spaces, regarding the social interaction of students.

The socio-behavioural characteristics of a physical setting is related with mental representations, architectural legibility, way finding, spatial identity and cognition as denoted by Lynch (Lynch 1960); Weisman (Weisman 1981, 189-204); Peponis (Peponis et al. 1990, 555-590); O'Neill (O'Neill 1991, 259-284); (Zeisel 1984, 166-171). Barker (Barker 1968, 183-193) suggested that, milieu, synomorphy and time are important components that identify the socio-behavioural nature of the space. Sociopetal and sociofugal settings bring people together or force them apart as describing the social interaction of space, while indicating physical characteristics of spatial configuration (Hall 1966, 70-75). Georgiadou (Georgiadou 2003), states that in settings where internal configuration produces easily supervised areas, positive opportunities for less rigorous control and autonomy are offered. On the contrary, configurations that subdivide internal space into differentiated areas, affect negatively this procedure, restrict independent movement and through this reduce the opportunities for socialization of children in residential care.

Visual qualities of spaces also determine the social interaction. Visual field along with postures, human body movements through transition spaces and levels affect the patterns of individual route choice and movement behaviour (Gibson 1950; Chang 2002, 582). As human body movement is affected by the distribution of obstacles and boundaries (Peponis et al. 2004, 453-473), additional aspects of visual information, experience and familiarity influences the route choice and decision behaviour (Chang 2002, 582). Visual connection with indoor and outdoor spaces is a critical issue. Salama (Salama 2008) presents a *POE* study of the performance of Qatar University campus and finds that most integrated key outdoor spaces and related furniture are not being used as intended due to physical insufficiencies such as shades or lack of quality, and therefore are contrasted with the architect's design philosophy. Social interaction between students in an important issue especially in educational facilities emphasizing informal education

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based on face to face relationships such as the architectural education itself. Sociopetal spaces extract more information about settings; they enrich the settings, and define the spaces as being more memorable and descriptive. Social interactive settings are not selected randomly, and their allocation is also in accordance with the capacity of visual field (Ünlü et al. 2001).

Social interaction can also be provided through a pedestrian flow in outdoor spaces, where the groups perceive a decrease of seclusion (Al-Homoud and Abu-Obeid 2003, 221). A research by Ghazzeh (Abu-Ghazzeh 1999, 764-804) exposed that outdoor spaces are focal points in student everyday behaviour while perception and use of outdoor spaces at a university campus is based on associated or anticipated behaviour at a given locus, and the physical parameters of the setting in relation to global cognition of the campus arrangement. Ghazzeh (Abu-Ghazzeh 1999, 764-804) also states that information about the place's objective attributes, about its affective quality, and about the behaviours that occur there are the three main factors that determines the perception of space and the choice of use. Outdoor scenery and presence of natural environment, especially water affects the location preferences (Purcell et al. 2001, 93). Tanner (Tanner 2000, 309-330) explains the importance of positive outdoor spaces for inviting nature to blend with the school's function and form. Outdoor spaces give a feeling that the school's learning environments are in harmony with nature and affects student's psychology.

This research focuses on the comparison of the frequency of students' occupancy in the interfacing areas of the ground floors and the syntactic values of these spaces both in clear and rainy weather comparatively. The interfacing spaces are denoted as a courtyard for ITU, and a seaside terrace for MSGSU. The time dependant usage of the extension of thresholds; i.e. the interfacing spaces, in terms of halls, yard, lawn, courts, halls, corridors and such, are the syntactic experiment areas of the research. The time dependent occupancy of students and the punctuation for the determined frequency in indoor/outdoor spaces are the preliminary testable comparison between the schools. The research hypothesis assumes that the frequency of the space usage by the occupants is linked to the spatial configuration of the environment, in terms of designed milieu, location type, visual capacity and integration.
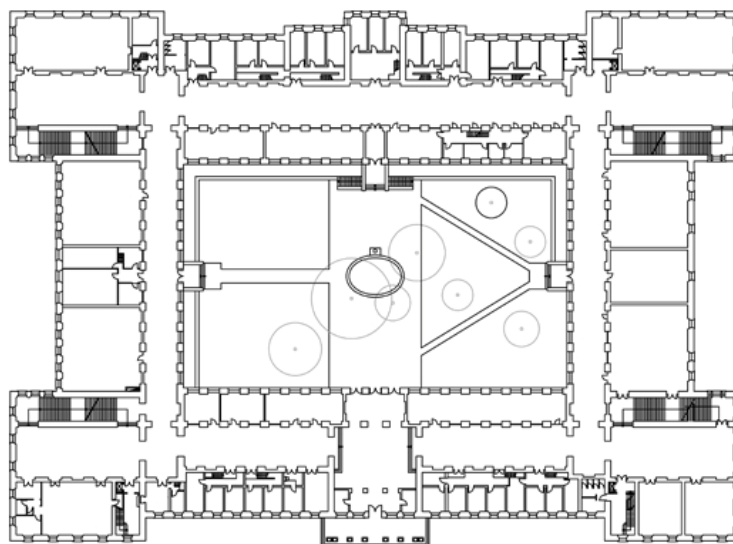
2. Case Study Area

Figure 1
Ground floor plan Taskisla - ITU

The two oldest state architectural schools of Istanbul compose the case area of this research. One of the buildings called Taskisla, houses the architectural faculty of ITU. This building was built in 1853 as a military hospital, used as military barracks and military courts in 1876; had gone through

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a restoration process during the period of 1944-1950, and finally was transformed into the schools of architecture and engineering. At present, the school has four main circulation towers connecting four wings. The general layout of the building is symmetrical and general appearances are identical. The courtyard level which is also the ground/entrance floor has many spaces allocated for exhibition, lounge and meeting spaces along with offices and other services (Figures 1 and 2).

Figure 2
Rainy and clear weather images from Taskisla – ITU

The second building which is located near Bosporus, houses the main campus of MSGSU. The building was originally built as twin seaside palaces for the two daughters of Sultan Abdulmecid in 1859. After the deaths of the princesses, one of the buildings were bought and used as the parliament while the other one housed other family members. School of Fine Arts was founded in 1882, and after many moving throughout the historical peninsula the school finally settled in the parliament building in 1926. In 1948, just before the huge fire that destroyed the palaces, the other building was serving as a girls' high school. When the restoration was somehow completed in 1953, the two palaces were connected with a buffer space now used as student cafeteria. Ground level which also has a sea side terrace has many spaces allocated for exhibition and lounge along with offices and other services (Figures 3 and 4).
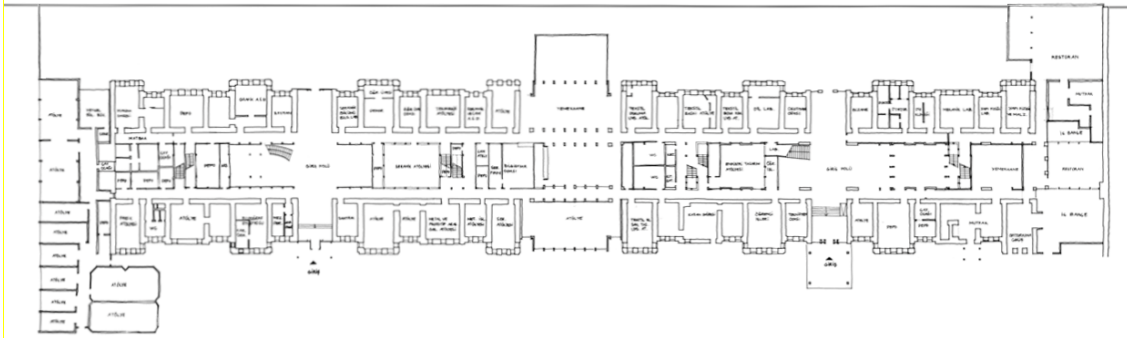
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Figure 3
Ground floor plan Findikli main campus - MSGSU

Figure 4
Rainy and clear weather images from Findikli main campus – MSGSU

3. The Definitions

The indoor/outdoor interface analysis in this study necessitates the investigation of different parameters in different weather conditions such as *functional attractiveness, milieu type, location type, real integration* and *isovist area*. Functional attractiveness refers to the functional values of space. Regardless of its kind, the occupancy of a space can be determined with a function attached to it. In the definition of "functional attractiveness", the aim is to examine the reason of occupancy of a single point and relating the occupancy of this point with the attraction power of its function in the campus analysed. Any socially attractive function in this sense such as a cafeteria, a small shopping unit, etc. related with the analyzed spaces is examined. If the analyzed space has the attraction of this kind, it means that the space is functionally attractive or a function related

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with the space exists. In this study, cafeterias, stationery shops, exhibition areas of both campuses are defined as functionally attractive areas and they are related with the parameter of *functional attractiveness*.

Milieu type defines an individual setting for every student in the analyzed areas. Every student involved in the study has a milieu as they occupy a point in the space and this milieu can be a designed, a semi-designed or a non-designed environmental point. If a student occupies a point with designed features such as sitting on a chair of a cafeteria, shopping from a book store's desk, etc. this milieu type is designed. A point can be occupied intentionally such as sitting on a small obstacle like a courtyard border wall, lying on the grass or sitting on the ground, etc. denoting a semi-designed milieu; whereas standing individually or with a group, on a corridor, on the pathways, in the courtyard or in any outdoor area refers to a non designed milieu.

Location type refers to a place where something happens or is situated. The location type can be outdoor, indoor and the interaction or interfacing spaces between indoor and outdoor spaces. The outdoor spaces are determined as the courtyard for ITU and the seaside terrace for MSGSU. These certain outdoor spaces are selected with a concern focusing on the syntactic comparison interface of indoor and outdoor spaces in two of the oldest architectural schools in Istanbul, in relation with student preferences. Both schools have outdoor spaces other than the selected ones; however, in the case of ITU the surrounding outdoor space is generally attributed by car park functions, and the building itself is oriented to its courtyard. In case of MSGSU the façade and narrow strip of front garden, facing north also have a heavy and noisy traffic load. The students of both schools are compelled to prefer the courtyard and the seaside terrace as outdoor spaces, in this sense. These outdoor spaces on the other hand, have interfacing relationships with the occupied areas of indoor spaces. *Location type* determines the outdoor, interfacing and indoor spaces. The indoor spaces are the locations where there's no visual connection with the specified outdoor space. The interaction or interfacing spaces are locations where visual contact is present with outdoor spaces although the mentioned point is indoors.

Real integration (RI) refers to a single value of a single occupied point in the related space derived from the edge partition analysis of the Spatialist software. Isovist area refers to value of visual field area of a single point in the related occupancy location.

The weather conditions in the study are eliminated into two types according to the time of observation and aim of the hypothesis in this study. *Rainy weather* is the weather in the mid day with clouds, rain and a temperature of approximately 10°C. *Clear weather* is the sunny weather in the mid day with a clear view and a temperature of approximately 18°C.

4. The Method

The ground/entrance levels of the buildings are examined through e-partition analyses; the level of visual stimulation of the spaces analyzed through isovists and social interaction level of the settings are also analyzed through time dependant observations. E-partition and isovist analysis are executed through Spatialist, while the data are evaluated through *SPSS*.

E-partition line analysis implemented in the ground floors both in rainy and clear weather conditions, has provided information about RI values. Visually integrated areas are denoted as red zones indicating more intersection and blue zones indicating less intersection. Low occupied and less used spaces are also considered and have an impact in this study. Since the study's aim is to look for the interfacing areas in the building's ground floor, all occupation levels of these spaces are at equal importance for this research. Low occupied and high occupied, less used and commonly used spaces are all analyzed in the study in order to determine the integration value, ie. occupation relations of spaces. Isovist area analysis applied mainly to selected occupied milieus that are highly used by students, such as circulation areas, courtyard for ITU, seaside terrace for MSGSU, functionally attracted areas and interaction spaces, gives us information about the perception levels of an inside, outside or an interface space point. The spaces that are used for administrative functions or that are not used by students are eliminated in this research.

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Interaction in this study is the effect of different variables to one another such as the occupation and the syntactic values of campus spaces. Here, syntactic values can be understood as real integration or isovist values of various points. The occupation level is affected by different variables such as location type, milieu type, and functional attractiveness of a space. In this sense, the interaction of indoor and outdoor spaces is important in order to understand the interfacing spaces between them. The interfacing spaces are also important to analyze the level of social interaction between the students in relation to the physical values of spaces.
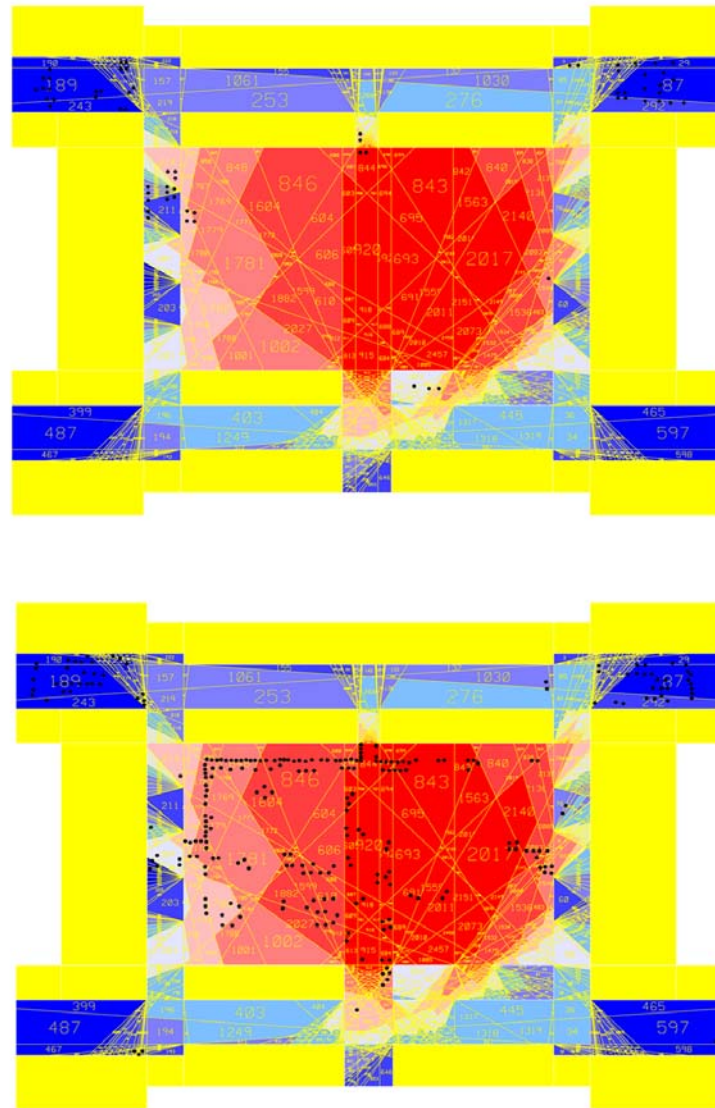

Figure 5

Occupation density and e-partition analysis of Taskisla in rainy weather (up) and clear weather (down)

Social interaction level is determined through observed parameters such as density of the occupants, within location and milieu type due to functional attractiveness in specific periods of time both in rainy and clear weather conditions. The density value is related with the count of passing students in a determined period on the selected zone. The observation period is set to be two times a day, at the peak hours selected between 10.00-12.00 and 14.00-16.00. Observations are executed within 30-minute intervals on the selected zones. The interactions less than 1 minute are eliminated from the records; postures are also indicated in accordance with behavioural modes. These observations are shown in figures 5 and 6.
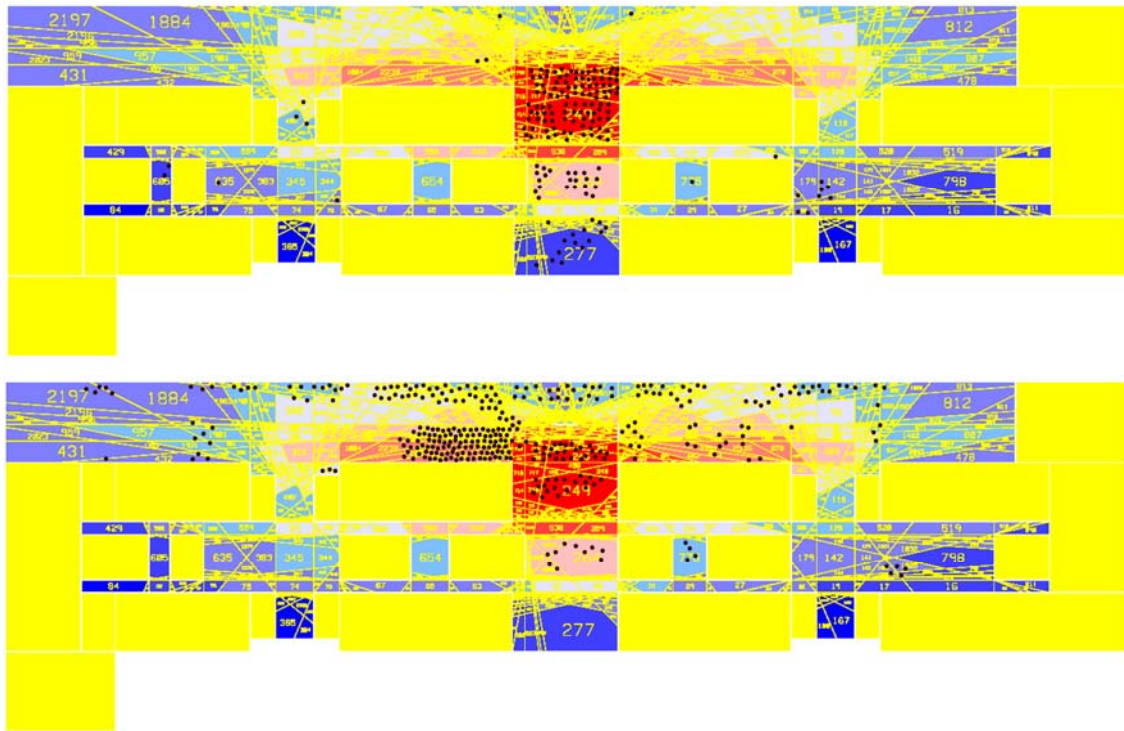
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Figure 6

Occupation density and e-partition analysis of MSGSU in rainy weather (up) and clear weather (down)

5. Data Analysis

This part of the study is examining the results of the data analysis between different parameters described in the definitions part of the research. E-partition and isovist analysis are executed through Spatialist, while the data are evaluated through SPSS. The observations in rainy and clear day conditions, values of different parameters are all included to data analysis.

RAINY		Milieu Type	Location Type	Integration Value	Isovist Area Value
	Functional Attractiveness	$X^2=25,920$ df$=2$ p<0.01	$X^2=14,603$ df$=2$ p<0.01	$X^2=10,246$ df$=2$ p<0.01	$X^2=11,084$ df$=2$ p<0.01
	Milieu Type		$X^2=35,088$ df$=4$ p<0.01	$X^2=29,575$ df$=4$ p<0.01	$X^2=30,014$ df$=4$ p<0.01
	Location Type			$X^2=47,708$ df$=4$ p<0.01	$X^2=37,673$ df$=4$ p<0.01

CLEAR		Milieu Type	Location Type	Integration Value	Isovist Area Value
	Functional Attractiveness	$X^2=20,894$ df$=2$ p<0.01	$X^2=50,000$ df$=2$ p<0.01	$X^2=42,604$ df$=2$ p<0.01	$X^2=44,939$ df$=2$ p<0.01
	Milieu Type		$X^2=25,051$ df$=4$ p<0.01	$X^2=23,183$ df$=4$ p<0.01	$X^2=24,801$ df$=4$ p<0.01
	Location Type			$X^2=69,231$ df$=4$ p<0.01	$X^2=50,000$ df$=4$ p<0.01

Table 1.

Rainy and clear weather correlations for ITU

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The statistical data analysis is executed through Pearson chi-square correlations and regression analysis tests of SPSS software. Expected X^2 values for p<0.01, p<0.02 and p<0.05 for df=2 are 9.210, 7.824, 5.991 and for df=4 are 13.277, 11.668 and 9.488 respectively. Tables 1 and 2 show the rainy and clear day results for ITU and MSGSU.

During the rainy days in ITU, indoor designed milieus, such as cafeterias, where the functional attractiveness is high but the RI values are lower, are highly occupied. In clear days, the occupation level of the courtyard is very high and the occupation is highly related with the higher RI values of spaces but the designed milieu factor is not affecting the occupancy levels of the spaces. The courtyard, which has a relatively low functional attractiveness value, has the highest occupancy level. Here the outdoor space factor is important, and the higher usage of interfacing areas in this sense has to be considered.

		Milieu Type	Location Type	Integration Value	Isovist Area Value
RAINY	Functional Attractiveness	X^2=6,268 df=2 p<0.05			
	Milieu Type			X^2=20,282 df=4 p<0.01	X^2=18,395 df=4 p<0.01
	Location Type			X^2=27,265 df=2 p<0.01	X^2=24,490 df=2 p<0.01

		Milieu Type	Location Type	Integration Value	Isovist Area Value
CLEAR	Functional Attractiveness	X^2=17,097 df=2 p<0.01	X^2=8,113 df=2 p<0.02	X^2=7,595 df=2 p<0.05	X^2=7,776 df=2 p<0.05
	Milieu Type			X^2=12,702 df=4 p<0.02	
	Location Type			X^2=18,722 df=4 p<0.01	X^2=18,393 df=4 p<0.01

Table 2

Rainy and clear weather correlations for MSGSU

During the rainy days in MSGSU, also high occupancy of the indoor designed milieus and locations are observed. Functional attractiveness of the highly occupied areas is always high for MSGSU during both rainy and clear days. The RI values of the highly occupied milieus are higher during the rainy days and lower during the clear days. The high occupancy level of clear days is seen in the seaside terrace, where the RI value is lower, but the functional attractiveness is high. During the clear days, the high occupation of lower integrated and functionally unattractive spaces is important. The occupancy of interfacing areas between the indoor and outdoor spaces is also important for clear days, where the flow from inside to outside has to be considered. However, the occupation of outdoor spaces is high for the clear days whereas the occupations of indoor and interfacing spaces are higher in rainy days.

When compared to "clear days' outdoor spaces' occupation" and "rainy days' indoor spaces' occupation", the interfacing areas are relatively low occupied, in both schools. The data analyses of all variables examined for the research are discussed in detail both for ITU and MSGSU respectively.

Rainy weather conditions attach importance to designed milieus, whereas in clear days the correlation between functional attractiveness and milieu type decreases denoting a relatively random occupancy in space for ITU. Students prefer to spend time in cafeteria and provided a

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shelter just in front of the courtyard doors in rainy days. For the case of MSGSU however, the correlations are milder, while students still prefer to spend time in the cafeteria, building entrances and staircases are also among favoured spaces of rainy days. Clear weather cases for MSGSU show higher correlation between functional attractiveness and milieu type denoting the relatively higher number of designed features and furniture in open spaces than ITU courtyard.

Correlations between functional attractiveness and location type are higher in clear weather days for both cases. Majority of ITU students prefer to spend time in functionally attractive, but deeper indoor spaces while majority of MSGSU students spend time in interfacing and shallower spaces in rainy weather conditions. In clear weather conditions ITU students prefer outdoor spaces rather than interfacing spaces, but functional attractiveness plays a major role here. While MSGSU students present a milder correlation majority of them, prefer outdoor and interfacing spaces regardless of the functional attractiveness.

In rainy weather conditions for ITU, the occupation level of low integrated spaces with function existence is twice the amount of low integrated spaces with no function existence. The majority of the occupancy is seen at the low integrated spaces where an attached function exists. In MSGSU, tendency is similar but no correlation exists. In clear weather however, although having dispersed in functionality, highly integrated spaces are also among the highest preferred locations for ITU students; whereas a mild correlation is seen for MSGSU students who prefer to spread alongside the terrace regardless of integration.

Functional attractiveness is related with isovist area in rainy days for ITU; the students prefer to settle on locations where they can check the circulation paths or courtyard density. In case of MSGSU however, the students prefer to occupy locations where they can check outside weather and entrance halls to a degree, rather than circulation paths. In clear days, closed system of ITU courtyard, present high visual areas for the occupiers, whereas, MSGSU terrace present a dispersed vista of an actually open system.

Milieu type and location is strongly correlated for rainy days in ITU, as the students highly prefer to occupy designed spaces, in clear weathers on the other hand, correlation decreases as the students may also prefer to occupy semi designed and non-designed outdoor spaces. There's a similar tendency in MSGSU also, however no correlation exists as there are more designed spaces outdoor and more semi designed spaces indoor in contrary to MSGSU. In both schools semi-designed or non designed interior spaces are not preferred in clear weather.

It is obvious that low integrated spaces with designed milieu features are mostly occupied during the rainy weather conditions. The correlations presented in both school cases support this case. In clear weather conditions however, correlations decrease slightly denoting the dispersed occupation of semi designed and non-designed places regardless of integration values. Milieu type and isovist area correlations are similar but slightly lower than RI relationship, for rainy days in both schools. However in clear days, correlation decreases and does not even exist in MSGSU case, still pointing out the dispersed nature of semi designed and non designed feature occupation in spaces.

It is presented that for interior location type in ITU case; only low integrated spaces are occupied during the rainy weather conditions. The integration level at the transition spaces is medium or low as are the levels of occupation. In MSGSU rainy day case, the high correlation points out the functional quality of the most integrated space as it also presents the highest preferred transition space. In clear weather conditions, the correlation degree for ITU increases, while for MSGSU decreases. The main reason of this situation is that the highest integrated spaces are located in the outdoor spaces, i.e. courtyard, and students prefer to occupy these spaces in fine weather. On the other hand, highest integrated spaces are located indoors, i.e. cafeteria and on transition areas in MSGSU that are not specifically preferred to occupy in fine weather.

Location type and isovist area evaluation, the values of ITU decreases in both cases, in relation to integration; whereas in MSGSU rainy day value decreases, while clear day value is stable. Rainy

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day values for ITU denotes a negative correlating stressing the importance of functional attractiveness and isovist area is not important for occupying the transition areas. In MSGSU case relation points out the dense occupation of transition and interfacing spaces. Clear day values on the other hand, shows an increase in occupation of visually integrated exterior spaces in ITU, while still dispersion is present through interior, exterior and transition spaces of MSGSU.

As for the regression analysis of the case areas, two parameters are taken into consideration. The dependent factor is *the density of the people in space* as the independent factor is *real integration value of space*. The density of the people in space refers to the number of students in the same convex shape with the same RI value. The rainy day and clear day density values are recorded separately. Regression analysis is investigated with the R values with significance between -1 and +1.

Rainy day results of ITU case, present negatively mild significance with values of R=-0.533, (p= 0,91>0,05). One of the reasons for such a relation may be the surplus of people occupying the same RI valued shape. The other reason is the functional preference of students, favouring the cafeteria facilities offered in low integrated spaces, thus disturbing the balanced distribution throughout the floor. For example, there are 33 students in one indoor s-partition shape, and another 30 students in another interior space, both occupying functionally social spaces. The total number of students in the analyzed areas of ITU measures up to 97 students, in rainy weather conditions.

Clear weather day results of ITU present no significance with values of R=0.333, (p= 0,317>0,05). The reason for such a relation is again the surplus of people occupying the same RI valued areas. For example, we see 108 students in the same outdoor area, i.e. courtyard occupying the same real integration valued partition, where the total number of students in the analyzed areas of whole ITU spaces is 267 students during the clear weather conditions. The highest integrated areas of the courtyard are not preferred for occupation, as a result of weather conditions. Sun light reflects on the milder integrated part of the courtyard thus, affecting the place selection in autumn.

Rainy day results of MSGSU case, present a positive significance with values of R=0.642, (p= 0,002>0,05). The reason for this kind of relation is the well-balanced occupancy values of the students in the analyzed areas. The well-balanced relation between the varieties of the different RI valued spaces and the occupancy numbers in these indoor or outdoor-indoor interfacing spaces is the reason of this relation. The highest integrated area of MSGSU is also one of the most functionally attractive locations of the building. This place serving as a cafeteria has a unique interface with the seaside terrace and also has a wide visual area that enhances the control of interior circulation paths, facilitating occupation preference in rainy days.

Clear weather day results of MSGSU present no significance with values of R=0.176, (p= 0,446>0,05). The result of this analysis actually, enhances the previous one, in which students prefer to occupy functionally and high integrated spaces in rainy day cases. In clear days however, students prefer to disperse alongside the Bosporus regardless of the RI assessments. However, there's also a surplus of people, measuring up to 170 students occupying the same integration shape in the terrace. This is an important amount because the total number of students in the analyzed areas of whole MSGSU spaces is 398.

6. Conclusion

This paper explored the interior, exterior and interface space occupation, preference density of two oldest architectural schools of Istanbul, in terms of climatic conditions and syntactic values. Regardless of integration or visual capacity, existence of a function or designed milieu features strongly affects to the location preference of students especially in rainy weathers. ITU students easily convert their interest to sociofugal spaces, given the necessary function. They expose stronger attachment to defined spaces whether interior or exterior, while they use interfacing spaces mainly for transition and circulation. The symmetrical design of the building also exposes a closed system itself with a central courtyard and presenting a highly integrated focal point that also enhances the students' preference of space occupation. On the other hand, MSGSU students prefer to occupy exterior and interfacing spaces, while they do not favour interior or low integrated

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spaces, regardless of its function. The longitudinal design of the building orients one to move through a defined path of rather narrow corridors. This situation encourages students to densely occupy the exterior and interfacing spaces. Level differences and small niches also enhance social interaction of students, but the existing sea level and Bosphorus panorama strongly affects the occupational preferences here.

Function is not related with syntactic values, if valid enough, function usually surpasses the integration quality especially indoors. Designed or not, presence of exterior spaces, and preferably a natural vista are crucial for academic life, and students do not need a defined function to enjoyably use these spaces. If interfacing spaces can form a niche, or a change in level, then they are preferred spaces of social interaction, if not, they act as undefined circulation paths or transition spaces.

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