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Retrofitting project evaluated in regard to architectural usability of buildings

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Abstract
This study was conducted to determine the effectiveness of spaces in representative retrofitted buildings in İzmir, Turkey, by developing usability indexes and basic descriptive evaluation criteria. This study first focused on the impact of retrofitting on certain biophysical aspects such as natural light, and thermal properties, together with also other building systems. Sample rooms/spaces were then categorised into four proposed effectiveness states according to the type of modification observed after retrofitting. Three simple usability indexes were used to rank samples with respect to their usability. Construction area added per construction area within room, construction area added per net usable floor area, and construction area added per total floor area based on basic spatial criteria. They were each analysed with regard to their effectiveness. Findings revealed that usability indexes were dependent on effectiveness states, and this objective method might be used in total building performance evaluation for retrofitted buildings. Further investigations were considered necessary for broader generalizations with improved results.

Keywords: *Architecture, retrofitting, usability, building performance, effectiveness, evaluation*

Introduction
The retrofitting process strengthens and redesigns a building which has not collapsed after an earthquake but has certain structural damage. **(**Arıkan et.al. 2005; Hamburger and Cole, 2001)**.** Although the type and level of damage having taken place, together with the type of the structural system, mainly determine how the retrofitting is designed, a number of other factors such as optimum cost, function and appearance of the building, plus its historic features, influence the method of structural retrofitting. Several types of retrofitting methods lead to structural modifications both in their dimensions and their material type, together with their configurations (Hamburger and Cole, 2001). Some of them are additions of new vertical elements, braced steel frame, shear wall or steel moment frame or application of diaphragm collectors and installing the reinforcing dowels. Thus, their impact on the cost, functions and appearance should be at a minimum level (Comerio et.al. 2006; Hamburger and Cole, 2001). Comerio et.al. (2006), in a report, also presented several hazardous buildings retrofitted by various structural improvement methods. While one method

created additional spaces or improved the facade quality, another blocked the transparency of the building or eliminated windows. This affected the natural light and air circulation in the building.

Consequently, the retrofit design may change spatial characteristics as well as some internal environmental aspects (Hamburger and Cole, 2001). By analysing types of rehabilitation methods we may discern how the design affects the net usable floor areas and construction areas, the amount of natural light and air inside, thermal properties and even the layout of furniture in spaces. The retrofit may result in poor functionality of the building i.e. spaces with high occupancy become unoccupied areas or become uncomfortable environments. To support this argument an investigation was conducted at the retrofitted buildings of Faculty of Architecture in İzmir to assess how retrofit affects usability of space.

Baird et.al. (1995, pp.165, 196) mention the effectiveness of spaces, and defined the usable area as “floor area of a facility assigned to or available for assignment to occupant groups or functions, including interior walls, building columns and projections, and secondary circulation”. In this study, architectural usability of rooms involves the term ‘the usable area’ within a room, together with its effectiveness. Effective rooms are defined as those which are designed according to facility requirements that are, functions and activities taking place in a building, for satisfying some set of criteria and norms, and enhanced by environmental requirements for visual conditions, ventilation and thermal properties. Architectural usability is defined here as how the occupation of space is influenced and how effectively the space is used after retrofitting.

Literature in the field of building evaluation techniques provides a general description of effective space in buildings and the Design Quality Indicator (DQI) to assess buildings (Baird et.al.1995; Construction Industry Council, 2008; Ding, 2008; Ornstein et.al. 2005; Wang and Jan, 2003). Functionality including use, access and space, deals with how a building is designed to be useful, and evaluates the adaptation of facilities to the occupants they serve. (Federal Facilities Council, 2001). In this study functionality is therefore one basic aspect to define architectural usability.

In this study the concept of architectural usability defines the basic evaluation procedure for structurally-retrofitted buildings of all types. It covers both physical and spatial information such as dimensions, shape and placement of spaces, furniture layout, and biophysical features such as natural light, natural air and thermal properties.

Retrofitting has been defined as strengthening a post-disaster structure such as one damaged in an earthquake in order to minimise damage from a possible earthquake and to avoid collapse of the structure under earthquake forces (Hamburger and Cole, 2001; Atımtay, 2001, Arıkan et. al., 2005; Wasti et.al. 2001). Several recent studies have been conducted concerning seismic performance of damaged buildings, seismic performance evaluation procedures (Sucuoğlu et. al, 2004; Oliveto and Decanini, 1998; Dönmez and Pujol, 2005. Lourenco and Roque, 2006; Hassan and Sozen, 1997), together with others about impact of architectural design on seismic performance (Özmen and Ünay, 2007; Atımtay, 2001). However, much of the focus in these studies has been on structural evaluation and retrofitting procedures and design faults in building configuration. The irregularities in plan and elevation (Arnold, 2001) are also explained explicitly in the Turkish Earthquake Code (Ministry of Public Works and Settlement, 2006). In contrast, how spatial characteristics of spaces, such as size, shape and layout, are affected due to the rehabilitation of post-disaster buildings is not particularly cited in reviewed studies (Sucuoğlu et. al, 2004; Oliveto and Decanini, 1998; Dönmez and Pujol, 2005. Lourenco and Roque,2006; Hassan and Sozen, 1997; Özmen and Ünay, 2007; Atımtay, 2001; Arıkan et.al. 2005). [and this is still assumed to be a question by the author].

In this study a simple quantitative approach based on basic floor and construction area ratios was developed to rank spaces according to their effectiveness due to the retrofitting design. Overall size and dimensions of inner spaces are just important to consider how to determine effective areas for occupants. They are basically related with facility requirements to satisfy occupants' activity, and it is assumed that they are in accordance with a set of norms and standards. However, it is necessary to focus on the change observed in the dimensions for both structural walls and columns and usable areas in spaces, and define environmental aspects modified. In other words, by developing simple indexes it would be possible to measure the degree of effectiveness of spaces in retrofitted buildings, and to offer a simplified assessment method in the field of building evaluation.

The overall aim of the study was to define basic-area ratios to evaluate usable space in retrofitted buildings in regard to modifications in spatial and environmental aspects. Including descriptions of impact on building systems, visual, thermal, and ventilating conditions, it would also provide feedback on architectural usability of spaces after retrofitting. This may guide architects and structural engineers to certain awareness in designing and applying seismic rehabilitation projects for damaged buildings, and in evaluating post-disaster buildings' performance. This study may also guide building owners and managers to a kind of awareness in making decisions about retrofitting or rebuilding the post disaster buildings. On the other hand, it may assist building owners and occupants in enhancing the quality of retrofitted buildings and their performance. It may also assist future researchers dealing with building evaluation techniques by way of the approach used in its implementation.

Physical facility

The subject buildings are associated with the Faculty of Architecture of İzmir Institute of Technology (İYTE) in İzmir. The report prepared by the President's Office under the establishment of İYTE mentions that the institution is one of the two high-technology institutes among universities in Turkey in which technology, advanced research, education, and production facilities are of prime importance.

Buildings belonging to the Faculty of Architecture are situated in the northern part of the campus on a hilly site as shown in Figure1. Office and studios are located both in a 4-story building (Block A) and in a 3-story building (Block B). While Block A is 4800 m^2, Block B is 4897 m^2 in total, as the schematical expression of the basic layout is shown in Figure 2. The story height for all floors is 4.00 m. There are a total of 80 rooms in Block A, and 42 rooms in Block B with various accommodation and layout. Each floor contains 8 studios and lecture rooms totally and a hall in-between them in Block B; Block A contains four floors, in the first of which is the cafeteria, the kitchen, entrance hall, conference hall, technical room and a store, while others have studios, offices and a computer laboratory. A general view from Block A just before the retrofitting process is shown in Figure 3.

Figure 1 *General view of İYTE Campus, İzmir (Source: Photo Gallery of IYTE; http://www.iyte.edu.tr/)*

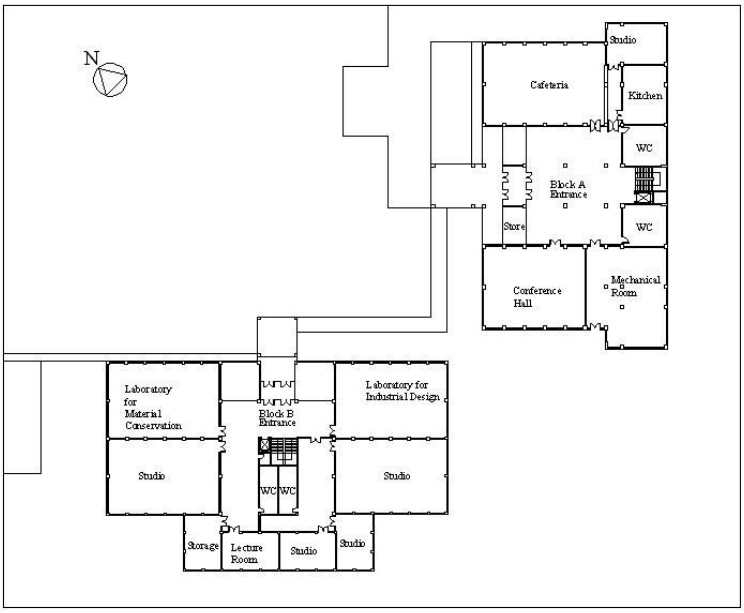

Figure 2 *The schematical plan showing Block A and Block B. (Source: the Department of Restoration Archive, İYTE).*

Figure 3 *Damaged building --Block A-- associated to Faculty of Architecture. (Source: the Department of Restoration Archive, İYTE).*

The building's construction was finished in 1999. Their structural systems were designed according to regulations in the Turkish Seismic Design Code published in 1974. Their structural skeleton was composed of reinforced concrete columns and beams with brick infill. A grid pattern was configured with square columns, whose sizes were 50 cm by 50 cm, and 60 cm by 60 cm in Block A. Column sizes in Block B were 50cm by 50 cm, and 40 cm and 40 cm. Brick wall partitions which were 20 cm in thickness defined the boundaries of rooms and halls.

Retrofit projects

These sample buildings were affected to different degrees by the 17th October (Mw=5,7 and Mw=5,9 USGS, Kandilli Observatory) and 21st October (Mw=5,9, USGS, Kandilli Observatory) 2005 earthquakes in İzmir. The city is in Zone 1 according to seismic regions of Turkey as shown in Figure 4. The Technical Seismic Evaluation Report prepared by Istanbul Technical University (ITU) depicted that some diagonal cracks were observed on some exterior and partition walls at ground floor level. At upper floor levels, however, certain horizontal and vertical cracks between structural elements and infill walls occurred (Figures 5 and 6). It was explained that the particular difference between lateral displacement of infill brick walls and those of structural columns caused this failure. In addition, the report stated that design irregularities were not observed in both horizontal and vertical layout according to Turkish Earthquake Code (Ministry of Public Works and Settlement, 2006). The calculated moment values, however, due to earthquake forces for most columns were higher than values for load bearing capacity of those both in X and Y direction. Thus the retrofitting project was proposed and applied to these buildings concerned with this report. This was because an earthquake with the same or a higher magnitude might reoccur and cause more serious damage to these buildings.

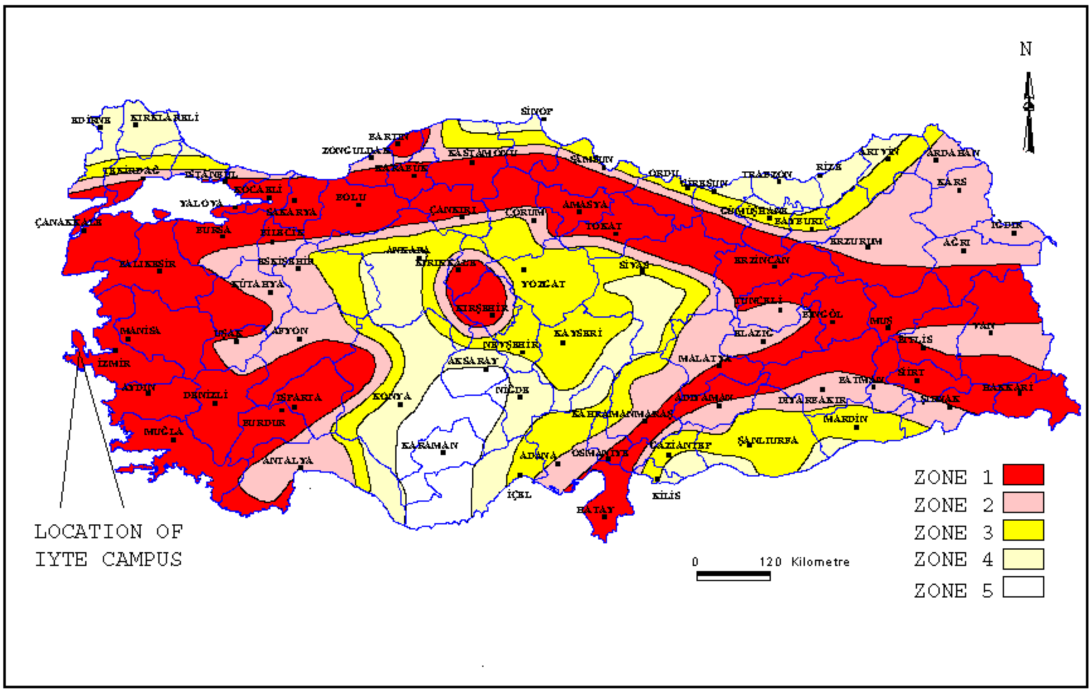

Figure 4 *The Seismic regions of Turkey and location of the campus (Source: Disaster and Emergency Management Presidency Earthquake Department, http://www.deprem.gov.tr/)*

Figure 5 *Exterior wall with diagonal and horizontal cracks viewed inside a room in Block A. (Photograph by Şebnem Young).*

Figure 6 *Exterior wall with cracks between structural members and infill material. (Photograph by Şebnem Young).*

In the seismic rehabilitation of the building, shear walls were added to the existing structural system and some interior columns were improved as shown in Figure 7. Shear walls were constructed between existing columns through a detailed construction process. First, existing infill brick walls were demolished at all floor levels starting from the upper floors, and ending at the foundation level. In order to strengthen the connection of the columns and new shear walls to the foundation, the soil around the foundation tie beams was taken out.

Figure 7 *Added shear wall inside Block A. (Source: the Department of Restoration Archive, İYTE)*

Figure 8 *Improved column detail with connecting steel bars. (Source: the Department of Restoration Archive, İYTE).*

The columns were enlarged with additional steel bars and stirrups, while continuity was achieved between floors by opening holes in the slab as shown in Figure 8. Steel bars were fixed inside the holes by using mortar with epoxy additive. The thickness of shear walls became 30 cm, while connected column dimensions were 70cm by 70 cm, 80 cm by 80 cm, and 90 cm by 90 cm at certain spaces. Some of these with column sizes and added shear walls are presented by schematic layouts of Block A and Block B in Figures 9 and 10, respectively.

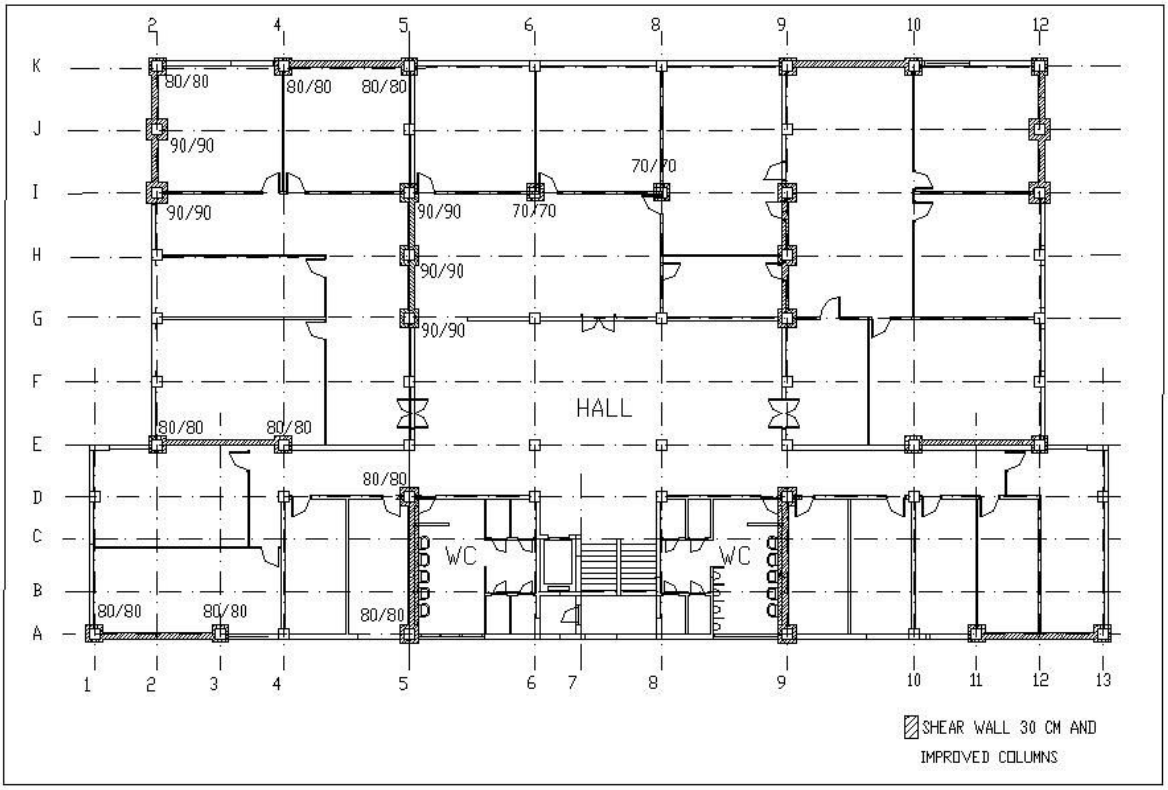

***Figure 9** Schematic drawing showing seismic rehabilitation of the structural system with added shear walls for Block A.*

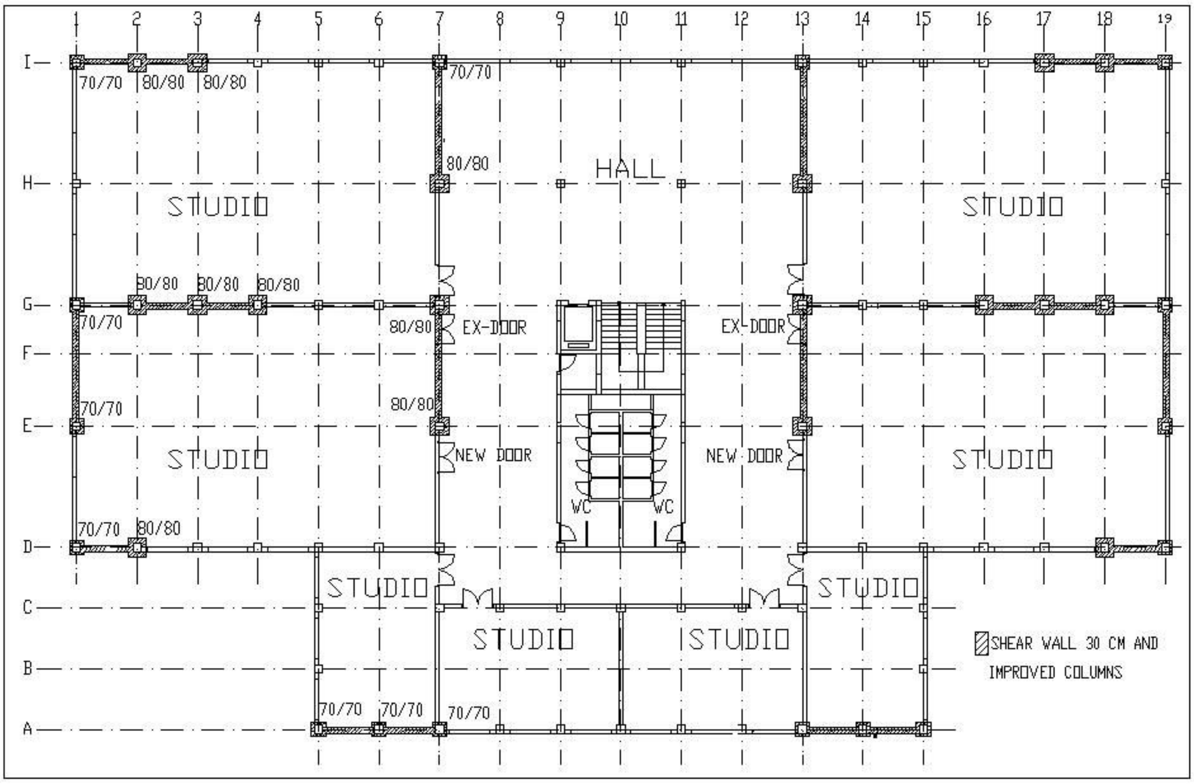

***Figure 10** Schematic drawing showing seismic rehabilitation of the structural system with added shear walls for Block B.*

Description of impacts after retrofitting

Comerio et.al. (2006), presented various structural improvement methods for hazardous buildings in the Campus of University of California, Berkeley. These methods not only supported the structural system but affected other building systems and requirements. For example, in one method, base isolators -steel reinforcing layers- constructed between the structure and the foundation created additional space underground for mechanical equipment. In another one, exterior concrete box columns enhanced the architectural expression of the building on exterior sides, and hollow boxes provided additional mechanical shafts. In a building steel cross braces blocked the vision through the entrance and thus affected the appearance. In another building the jacketing method eliminated some windows thus blocking vision and light for working areas but improved the façade aesthetically. The report prepared for the buildings in Campus of University of California, Berkeley provides information about architectural modifications in each structural retrofit process by observation. To document and to prove their impact on buildings and occupants, detailed quantitative surveys need to be carried out.

Several evaluation survey techniques have been mentioned in the literature. One method offered by Ornstein et.al. (2005) for the evaluation of thermal and visual comfort is to take physical measurements in the field survey then conduct a questionnaire on the user satisfaction level and finally compare data in regard to the assessment for occupants' responses. In another study environmental measurements including visual, thermal, acoustical and dimensional parameters were correlated with user satisfaction assessments. (Baird et.al.,1995). In contrast to the previous studies, Wong and Jan (2003) proposed a total building performance evaluation which involved a comparison of data obtained from field measurements and requirements set out in certain standards and guidelines.

This qualitative approach focuses on some biophysical aspects such as natural light and thermal properties, together with other building systems, although, through a basic use of descriptive evaluation criteria. It was still assumed that all these systems were constructed according to certain standards and guidelines so the recommended design values were not judged or evaluated in this study. However, any modification/deficiency witnessed/predicted for relevant environmental and building systems after retrofitting are outlined in detail below and are summarized in Table 1. Their verifications are based on information in literature mentioned below.

It is known that the layout of windows and their dimensions may severely limit the amount of natural light available in a room (Egan, 2002; Moore, 1993). After retrofitting, window openings were filled with concrete due to the construction of new shear walls. Thus, daylighting level was decreased. Electric lighting became essential throughout the day and electrical energy consumption became high. As a dim working environment would be unfavourable for occupants' mood and would reduce their productivity (Walden, 2005, pp.118), new activities were assigned for such rooms. An office was assigned to be a rarely-used-storage.

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To determine heating system and to calculate heat transfer through exterior walls, their type, thickness and windows are significantly effective (Moore, 1993). Thus, after retrofitting, the new exterior wall material (concrete) and the reduced opening sizes created new heat loss/gain values for that room. Thus energy consumption should be recalculated for the new condition. Otherwise, operational costs would be high, and uncomfortable environment would reduce working performance.

Retrofitting also created some non-structural brick walls which would lead to certain modifications on sanitary systems and joinery systems. In the WC, for example, the sanitary piping was housed in an additional brick wall next to the shear wall. This reduced the net usable area and changed the layout of pipes. Thus, it increased the construction costs, and maintenance process.

Table 1 *Summary of several outcomes due to the impact of retrofitting on environmental aspects and building factors*

Visual	Thermal	Ventilating	Building systems
Daylighting level	Heat loss/gain values	Natural air level	Infill walls
Electricity consumption	Energy consumption	Indoor air quality	Suspended ceilings
Occupants' mood	Working performance	Occupants' mood	Access to rooms
Working performance	Operational costs	Learning process	Sanitary systems
Assigned to another function		Assigned to another function	Layout of furniture

Material

The material itself as architectural production drawings was obtained from the Department of Works in İYTE. A total of 101 rooms/spaces in both Block A and Block B were the subject of this study. They were categorized according to their functional distinction as shown in Table 2. Their alphanumeric identity codes designated on production drawings were used for each sample element to keep track of operations. All floor plans of the two blocks were used, as the investigation proper was specifically delimited to the basic floor area measurements.

__Table 2__ Total number of samples according to their functional distinction.

Location	Office	Studio	Serving area (wc,storage,meeting room, library)	Circulation area (hall, corridor)	Total no. of rooms
Block A	28	17	15	8	68
Block B	0	22	8	3	33
Total no. of rooms	28	39	23	11	101

Areas calculated for this study included: net usable floor area, that is, the area available for the occupant groups and specified functions, and calculated from the internal (wall-face-to-wall-face) dimensions for each room given on a floor plan; total floor area, that is, the overall built on area calculated from the external perimeter dimensions given on a floor plan; construction area within space, that is , the cross-sectional area of structural wall and columns inside the net usable floor area; and construction area added, that is, the extended cross-sectional area of structural elements after retrofitting inside the net usable floor area.
Change in both physical and biophysical properties occurred in rooms after retrofitting were classified according the layout of additional structural elements. The descending format of the categories below indicates the increasing impact of change in spaces. Also displayed is the descending magnitude of the effectiveness. Definitions of the effectiveness state are related to these as follows;

Effect 4: No change for any of these aspects after retrofitting.

Effect 3: Spaces with additional structural walls facing interior. For this condition, replacement of interior doors was observed, but no change took place in any environmental aspects.

Effect 2: Spaces with additional structural walls facing exterior. For this condition, either windows were replaced with structural walls or their dimensions were modified. Heat loss/gain capacity of exterior wall material plus the amount of light passing through windows and the amount of natural air inside were affected and changed.

Effect1: Spaces with additional structural walls facing both interior and exterior. All conditions mentioned for both Effect 2 and Effect 3 were valid in this category.

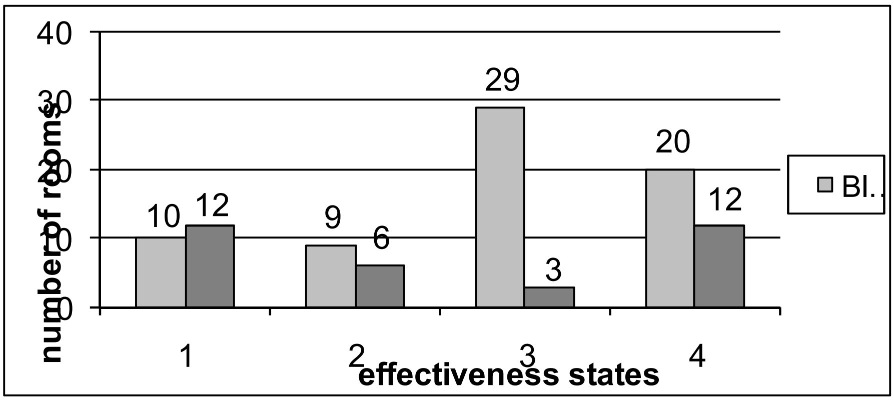

Figure 11 *Distribution of samples according to their effectiveness.*

All rooms located in Block A and Block B were categorized according to their effectiveness states, as shown in Figure 11. There were 32 rooms out of 101 in Effect 4; other 32 out of 101 in Effect 3 with minor spatial modifications. For Block A, 9 out of 68 were in Effect 2, while other 10 out of 68 was in Effect 1. The number of rooms in which retrofitting lead to major modifications for both spatial and biophysical aspects –that is rooms in Effect 1 and 2- were less than others in Effect 3 and 4; 22 out of 101 in Effect 1, and 15 out of 101 in Effect 2.

Proposed procedure

The study was designed and constructed in accordance with due simplified indexes and statistical analyses. These indexes are considered merely as simple indicators of possible usability of spaces in retrofitted buildings and here they are labelled ‘usability indexes’, but not should be understood as general quantitative building performance assessment tools. Measurements and calculations were based on production drawings while evaluation consisted of Analysis of Variance (ANOVA).

Data Compilation

Data sheets, listing all samples (rooms/spaces) with descriptive and quantitative features derived from the material (production drawings) were first constructed for quick tabulation of calculated areas. Thus, recorded were room/space designations, net usable floor areas, the construction areas within each space before/and after retrofitting, and construction area added for each space after retrofitting, together with total floor areas for each floor. Effectiveness state, as categorised by the author, and functional description for each space, such as, office, studio, utility rooms such as WCs, and circulation areas such as corridors, halls were also noted. In addition, after the earthquake and during the retrofitting construction several photographs were taken by researchers in the Department of Architecture and Department of Restoration, while walk-through observations were conducted for several days in order to determine hazardous structural elements, then, retrofitted structural elements, and to identify spatial and environmental conditions in spaces, together with other building systems.

Usability Indexes:
These are simplified quantitative ratios based on usable space and structural elements' dimensions. To rank rooms/spaces with respect to their effectiveness, various combinations of simple parameters were tried, and certain scalars were developed. As an example, these indexes for rooms/spaces in the third floor of Block A are shown as a tabular form in Table 3.

Table 3 *Usability indexes for a group of sample in Block A. (rooms/spaces in the third floor).*

Sample	**Floor**	**Effective**	$\mathbf{A_{NUF}}$	$\mathbf{A_{CA}}$	$\mathbf{A_{TF}}$	$\mathbf{R_1}$	$\mathbf{R_2}$	$\mathbf{R_3}$
office	3	2	35,40	0,90	1224	0,709	0,025	0,00074
office	3	2	35,38	0,60	1224	0,619	0,017	0,00049
office	3	4	14,29	0,19	1224	0,559	0,013	0,00016
office	3	4	23,08	0,00	1224	0,000	0,000	0,00000
office	3	3	47,50	1,87	1224	0,806	0,039	0,00153
office	3	3	33,75	0,15	1224	0,500	0,004	0,00012
office	3	2	36,13	0,57	1224	0,655	0,016	0,00047
office	3	4	18,64	0,00	1224	0,000	0,000	0,00000
office	3	3	18,59	0,57	1224	0,792	0,031	0,00047
hall	3	4	19,85	1,16	1224	0,436	0,058	0,00095
office	3	3	18,59	0,57	1224	0,792	0,031	0,00047
office	3	4	18,64	0,00	1224	0,000	0,000	0,00000
office	3	4	18,64	0,15	1224	0,500	0,008	0,00012
office	3	2	18,64	0,15	1224	0,652	0,008	0,00012
office	3	2	29,46	0,15	1224	0,333	0,005	0,00012
office	3	4	34,10	0,24	1224	0,444	0,007	0,00020
office	3	4	35,23	0,16	1224	0,348	0,005	0,00013
office	3	3	51,22	0,54	1224	0,711	0,011	0,00044
office	3	1	71,01	2,36	1224	0,776	0,033	0,00193
office	3	2	35,37	0,90	1224	0,231	0,025	0,00074
office	3	4	35,12	0,18	1224	0,429	0,005	0,00015
office	3	3	48,74	2,18	1224	0,858	0,045	0,00178
storage	3	3	16,21	0,11	1224	0,786	0,007	0,00009
meeting room	3	3	68,28	0,64	1224	0,727	0,009	0,00052
hall	3	4	195,55	1,16	1224	0,436	0,006	0,00095

The first ratio is the construction area added per construction area within space. This was taken as a basic indicator of the level of increase in the cross-sectional area that the structure occupied within that space. It reflects the level of construction efficiency, representing the magnitude of the modification in cross section areas of structural walls and columns. The larger it was, the less usable area would be available, and would be less effective. The first ratio reads:

$$R_1 = A_{CA} / A_{CW} \quad (1)$$

where A_{CA} is the construction area added in retrofitting construction, and A_{CW} is the total construction area within space.

The second is the construction area added per net usable floor area before retrofitting. This was taken as a simple ratio to assess the magnitude of the modified area which serves occupants, again on the assumption that the larger it was, the less area would be usable by occupants. The second ratio reads:

$$R_2 = A_{CA} / A_{NUF} \quad (2)$$

where A_{CA} is the construction area added in retrofitting construction, and A_{NUF} is the net usable floor area before retrofitting.

The third is the construction area added per total floor area. This was taken as a direct indicator of priority values for each occupiable space after retrofitting. This ratio is an indicator for defining the density of structural members (Arnold, 2001) and construction costs (Hardy and Lammers, 1986). The less value for this leads to a high degree in effectiveness. The third ratio reads:

$$R_3 = A_{CA} / A_{TF} \quad (3)$$

where A_{CA} is the construction area added in retrofitting construction, and A_{TF} is the total floor area.

The scatter charts were developed to represent the ranking for effectiveness, as shown in Figure 12. This procedure was considered to be the most efficient. Each room/space was represented by a point in two-coordinate representations. Plotting the values, for example, for R_3 (the construction area added per total floor area) in y-axis against R_2 (the construction area added per net usable floor area before retrofitting) in x-axis resulted in a plausible ranking representation to reflect the categories offered for effectiveness, as shown in Figure 10a. The average R_2 and R_3, in Figure 12a; R_1 and R_3, in Figure 12b; and R_1 and R_2, in Figure 12c, were observed to decrease while values for effectiveness levels were increasing, indicating larger usability for retrofitted rooms/spaces with minor changes. However, it is not a procedure to predict building performances. It is simply an objective method to rank rooms/spaces in a retrofitted building with respect to their usability.

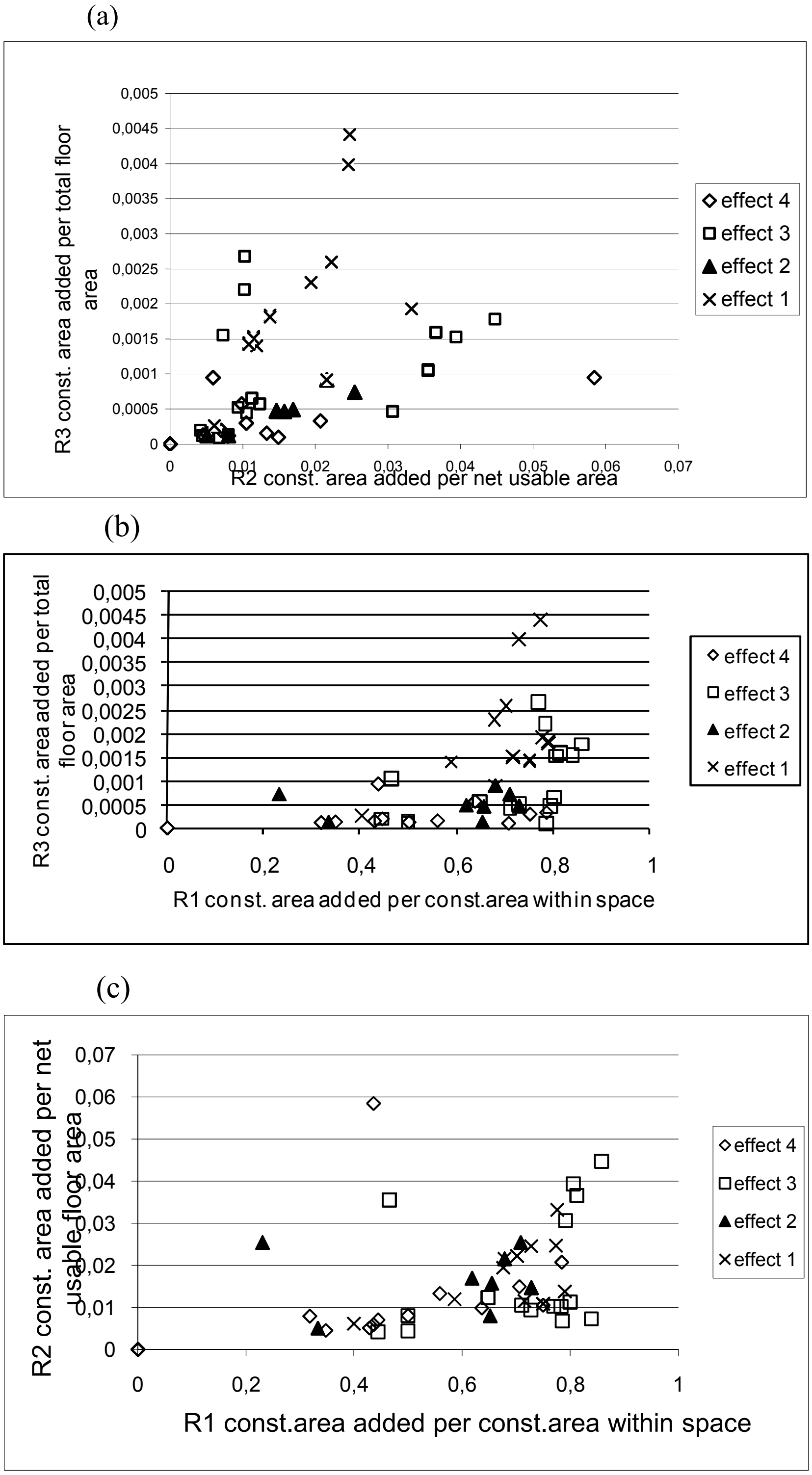

Figure 12 *Scatter plots for (a) R 2 and R 3, (b) R 1 and R 3 , (c) R 1 and R 2 reflecting effectiveness states*

Data Analysis

The relations between variables (ratios) by which the author means, construction area added per construction area within space, construction area added per net usable floor area before retrofitting, construction area added per total floor area were analysed by single-factor Analysis of Variance (ANOVA). Excel for Windows was used in conducting these tests and in the preparation of tables showing their results. Three factors were analysed by analysis of variance at 5% level of significance (α=0.05). These were:

i) the difference between effectiveness state and R_1 --construction area added per construction area within space--;

ii) the difference between effectiveness state and R_2 --construction area added per net usable floor area before retrofitting--; and

iii) the difference between effectiveness state and R_3 --construction area added per total floor area.

Results

Raw data was first compiled according to net floor areas, construction areas and total floor areas. All rooms were identified according to their effectiveness state and usability indexes. These related to construction area added per construction area within space, construction area added per net usable floor area before retrofitting and construction area added per total floor area. Ratios were evaluated according to effectiveness state. These are Effect 1, Effect 2, Effect 3 and Effect 4.

The results of the Analysis of Variance according to mentioned variables are presented below, with the tabular form for each of these given as Table 4, Table 5, and Table 6, respectively.

a) The null hypothesis was H_0: τ_i=0; i.e. There is no relation between effectiveness state and the construction area added per construction area within space. Accordingly, H_0 was rejected; meaning that the construction area added per construction area within space was not independent of the room's effectiveness.

Table 4 *ANOVA for construction area added per construction area within space in regard to their effectiveness state.*

Source of Variation (CRF)	Degrees of Freedom (df)	Sum of Squares (SS)	Mean Squares (MS)	ρ value	Calculated F-value (MS AG) (MS WG)	F expected (α=0.05, 1,158)
Among Groups, (AG)	3	3,647627	1,215876	2,34229E-14	31,66349	2,6984
Within Groups, (WG)	97	3,724794	0,0384	---	---	------
Totals	100	7,372421	---	---	---	---
Conclusion: Ho is rejected at 95% confidence.						

b) The null hypothesis was H_0: τ_i=0; i.e. There is no relation between effectiveness state and construction area added per net usable floor area before retrofitting. Accordingly, H_0 was rejected; meaning that the construction area added per net usable floor area before retrofitting was not independent of the room's effectiveness.

***Table 5** ANOVA for construction area added per net usable floor area before retrofitting in regard to their effectiveness state.*

Source of Variation (CRF)	Degrees of Freedom (df)	Sum of Squares (SS)	Mean Squares (MS)	ρ value	Calculated F-value (MS AG) (MS WG)	F expected (α=0.05, 1,158)
Among Groups, (AG)	3	0,101293	0,033764	1,26E-07	13,93476	2,6984
Within Groups, (WG)	97	0,235034	0,002423	---	---	------
Totals	100	0,336327	---	---	---	---
Conclusion: Ho is rejected at 95% confidence.						

c) The null hypothesis was H_0: τ_i=0; i.e. There is no relation between effectiveness state and construction area added per total floor area. Accordingly, H_0 was rejected; meaning that the construction area added per total floor area was not independent of the room's effectiveness.

***Table 6** ANOVA for construction area added per total floor area in regard to their effectiveness state.*

Source of Variation (CRF)	Degrees of Freedom (df)	Sum of Squares (SS)	Mean Squares (MS)	ρ value	Calculated F-value (MS AG) (MS WG)	F expected (α=0.05, 1,158)
Among Groups, (AG)	3	0,003642	0,001214	3,159486 5536804 4E-06	10,88557	2,6984
Within Groups, (WG)	97	0,010819	0,000112	---	---	------
Totals	100	0,014462	---	---	---	---
Conclusion: Ho is rejected at 95% confidence.						

Discussion

As there was no evidence in the literature of studies carried out on the architectural usability evaluation of buildings after seismic rehabilitation it was not possible to compare these results with previous researches.

Though derived from a study of limited scope on two retrofitted buildings resembling only one certain type of seismic design for one type of building, a number of results concerning usability of retrofitted buildings were considered notably on their own merit .One was the dependence of R_1 on effectiveness, despite structural elements in the room showing specific differences in regard to their layout and type, i.e. columns or shear walls. While the analysis method precluded identification of particular rooms to which these differences could be ascribed, informed opinion suggested that this would most likely be those rooms in which not only the structural elements damaged but particularly all those that were strengthened during retrofitting; although the emphasis for its reason seemed to be on the larger values for cross-sectional areas of structural elements. Another relevant outcome was to be the structural efficiency in regard to the load carrying capacity of elements; for example, an enlarged column would continue to carry the same amount of dead load (the weight of beams and slabs) after retrofitting, although it could carry more. Of course this feature requires dedicated further study.

Another aspect of interest was the dependence of R_2 and R_3 on effectiveness; the former due to the rate of magnitude for the modified construction area in rooms, and the latter in regard to that rate in floors. Both ratios represented the density of structural elements for one specific room and for rooms on one identical floor respectively. Certain ratio between net usable floor area and total floor area determines the cross-sectional area for shear walls (Sucuoğlu et.al.2004), and they have priority in seismic performance of buildings (Arnold, 2001). Thus, it was indeed a rather particular finding that such indicators were valid not only for structural research but also in building assessment studies. Finally, it was concluded that the larger values for each of these indicators would result in less effective spaces in retrofitted buildings subjected in this study.

Alongside these outcomes were the scatter charts regarding effectiveness states. They represented rankings with the usage of usability indexes, namely, $R_{1,}$ R_2 and $R_{3.}$ Although it seemed to be that their usage was limited to rank rooms/spaces with respect to their usability in regard to spatial criteria, they would act in a simplified evaluation method including more variables than it had in further investigation. Such variables might be lighting level, temperature, humidity, air flow, indoor air quality, furniture arrangement, and size of furniture to develop effectiveness classifications for retrofitted buildings.

Though subjective evaluations for the environment referred to by Wong and Jan (2003), Ornstein et.al. (2005), and Baird et. al. (1995), and physical measurements to quantify environmental requirements were not conducted in this study, it is expected that a further investigation including occupants' responses may reveal reliable outcomes for the impact of retrofitting on a building's total performance. Another study including measurements would also show the degree of the impact of retrofitting. In relation to the economic assessment of the seismic retrofitting proposed by Arıkan et.al.(2005), the impact of retrofitting on people and processes may be employed in a further financial analysis which will provide background knowledge to make comparison between all building systems in two situations (before and after retrofitting) and to decide whether to rebuild or to retrofit.

Conclusion

As almost all the literature has indicated earthquake-damaged buildings are strengthened by retrofitting which may affect their spatial, operational and environmental requirements. Just as they may change the net floor area used in spaces, they influence the physical characteristics of space or the accommodation throughout the facility. The study outlined above dealt with usability of spaces to evaluate retrofitted buildings; together with descriptions of impact occurred on biophysical aspects, such as visual, ventilating and thermal ones. Usability indexes were proposed to rank rooms/spaces in regard to quantified variations in terms of spatial aspects. While the findings show dependency of these indexes on rooms' effectiveness, they could be generalised no further than the case at hand, but only by a high number of samples attained in future. Thus in further studies it may be possible to improve these indexes by investigating a comparatively high number of buildings with various functions. Further research may include measures for the biophysical state of the impacted spaces to define the magnitude of change, or include post-occupancy data on user perception along these biophysical parameters. More detailed and noteworthy results may be attained.

This study provides feedback about what type of impact may occur due to retrofitting in spatial and environmental conditions and how it affects processes and organizational culture. The ranking process showed the distribution of rooms in various stages of effectiveness due to relevant indexes. Additional variables mentioned in Discussion may enhance the total evaluation method for retrofitted buildings. Such an evaluation process then may enable building managers, owners and users to become aware of the deficiencies and impact on usability of spaces due to retrofitting. Such persons may benefit from this by predicting outcomes before decision making or whether to rebuild or to retrofit, and by assessing the cost-benefit of retrofitting. Further researchers interested in architectural assessment of retrofitted buildings may benefit from its methodological approach.

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Bu çalışmada, kullanılırlık indeksleri geliştirerek ve basit tanımlayıcı değerlendirme kriterleri ile mekanların etkinliğini tanımlamak amacıyla İzmir'de (Türkiye) örnek olarak seçilen deprem sonrası yapısal güçlendirme uygulamaları yapılmış binalar incelenmiştir. Araştırma öncelikle güçlendirmenin biyofiziksel etkenler olan doğal ışık ve ısısal özellikler ile beraber ayrıca diğer yapısal sistemlere olan etkisi dikkate alınmıştır. Örnek mekanlar, güçlendirme çalışmasından sonra gözlemlenen çeşitli değişiklikler göz önünde bulundurularak önerilen etkinlik derecelerine göre sınıflandırılmış, dört gruba ayrılmıştır. Bir sonraki aşamada, örneklerin kullanılırlıklarına göre sıralanabilmesi için üç basit kullanılırlık indeksi geliştirilmiştir. Güçlendirme sonrası eklenen yapısal alanın oda içindeki toplam yapısal alana oranı, eklenen yapısal alanın net kullanım alanına oranı ve eklenen yapısal alanın toplam yapı alanına oranı indeksleri basit mekansal kriterlere dayandırılmıştır. Her bir mekan etkinliği açısından incelenmiştir. Bulgular, kullanılırlık indekslerinin mekanların etkinlik derecelerine bağlı olduğunu ortaya çıkarmıştır. Bu nesnel yöntem, güçlendirilmiş binalar için bina performansı değerlendirmesi amacıyla kullanılabilir. Sonraki araştırmalar, daha geliştirilmiş ve daha genel sonuçlar çıkarmak için gerekli görülmüştür.

Yapısal iyileştirme, deprem sonrasında yıkılmamış ama deprem sırasında belirli bir miktar hasar görmüş binanın yeniden tasarlanması ve güçlendirilmesi yöntemidir. Taşıyıcı sistemin ne olduğu, hasarın çeşidi ve derecesi iyileştirmenin nasıl tasarlanacağını belirlese de, binanın dış görünüşü, fonksiyonu ve maliyet yapısal iyileştirme yöntemini etkileyen faktörler arasında yer almaktadır. Betonarme perde duvarların eklenmesi, mantolama ile yapısal elemanların boyutlarının artırılması veya bina dış çeperine payandalar tasarlanması gibi çeşitli iyileştirme yöntemleri, yapısal elemanların boyutlarını, kullanılan malzemeyi ve konfigürasyonlarını değiştirmektedir. Bahsedilen yöntemler, binaların taşıyıcı sistemlerini güçlendirmekle kalmaz, diğer yapısal sistemleri ve bazı bina gereksinimlerini de etkiler. Örneğin, Bina dış yüzeyinde uygulanan payandalar ya da yeni taşıyıcı elemanların pencere gibi açıklıkları kapatması, iç mekanlara doğal ışık alınmasını engellemekte cephenin mimari karakterini de değiştirmektedir.

Bu çalışma için İzmir Yüksek Teknoloji Mimarlık Bölümü yapısal iyileştirme uygulaması yapılan binalar seçilmiştir. Söz konusu yapılardan A Blok 4800 metrekare, B blok ise 4897 metrekare alanı ile ofis, stüdyo ve derslikleri barındırmaktadır. İzmir 17-21 Ekim 2005 depremleri binalarda hasar oluşmasına neden olmuştur. Taşıyıcı elemanlarda ve dolgu duvarlarda düşey ve yatay çatlaklar meydana gelmiştir. Bu nedenle, yapısal sistemi güçlendirmek için iyileştirme projesi hazırlanmış ve uygulanmıştır. Grid sistemde yerleştirilmiş 40X40 cm, 50X50cm ve 60X60cm'lik betonarme kolonlar ek donatı kullanılarak 70X70cm, 80X80cm ve 90X90cm lik boyutlarda genişletilmiş, belirli yerlere 30 cm lik betonarme perde duvarlar eklenmiştir.

İyileştirme uygulaması yapısal sistemdeki değişikliklerle beraber diğer sistemleri ve bazı biyofiziksel unsurları da etkilemiştir. Mekanların doğal aydınlatma ve ısısal özelliklerindeki değişiklikler sözel değerlendirmelerle açıklanmıştır

Bu çalışma kapsamında A ve B bloklarda toplam 101 oda incelenmiştir. İyileştirme projesine ait kat planlarından basit alan ölçümleri yapılmıştır. Hesaplanan alanlar arasında net kullanım alanı (odanın duvardan duvara alınan iç ölçüleri ile hesaplanır); toplam kat alanı (kat planının dış çeper ölçüleriyle hesaplanır); oda içi yapısal alan (yapısal elemanların net kullanım alanı içine giren kesitsel alanı olarak hesaplanır); eklenen yapısal alan (iyileştirmeden sonra net kullanım alanı içinde genişletilmiş kesitsel alan olarak hesaplanır).

Mekanlar, güçlendirme projesine göre eklenen yapısal elemanların yerleşimine göre ve buna bağlı olarak odaların fiziksel ve biyofiziksel özelliklerindeki değişikliklere göre dört grupta sınıflandırılmıştır. Azalan biçimde isimlendirilmiş sınıflar mekanlardaki değişikliğin artan etkisini göstermektedir. Aynı zamanda etkinlik derecelerinin de azaldığını ifade eder. Etkinlik derecelerine göre sınıflandırmalar şöyle tanımlanabilir;

Etkin 4: Herhangi bir yapısal eleman eklenmemiş mekanlar bu gruba dahil olmakta, iyileştirme uygulamasından sonra da herhangi bir fiziksel ya da biyofiziksel özellikte bir değişiklik gerçekleşmemiştir.

Etkin 3: Eklenen taşıyıcı duvarları iç çeperlere yerleşmiş mekanlar bu gruba dahil olmakta, bazı oda kapılarının yerleri değişmiş ama biyofiziksel özelliklerde (çevresel koşullarda) herhangi bir değişiklik gözlenmemiştir.

Etkin 2: Eklenen taşıyıcı duvarları dış çeperlere yerleşmiş mekanlar bu gruba dahil olmakta, bazı pencerelerin yerini taşıyıcı duvarlar doldurduğu için pencere tamamen kapanmakta yada bazılarının boyutları değişmektedir. Dış çeper duvarının malzemesi değiştiği için ısıl performans özelliği değişmekte, pencerelerdeki değişiklik nedeniyle de odaya giren doğal ışık miktarı azalmaktadır.

Etkin 1: Eklenen taşıyıcı duvarları iç ve dış çeperlere yerleşmiş mekanlar bu gruba dahil olmakta, Ektin 2 ve Etkin 3 için geçerli olan tüm değişiklikler bu sınıfa dahil odalar için geçerli olmaktadır.

Söz konusu mekanları kullanılırlığına(etkinliğine) göre derecelendirebilmek için de kullanılırlık indeksleri önerilmiştir. Bunlardan ilki, güçlendirme sonrası eklenen yapısal alanın oda içindeki toplam yapısal alana oranı(R1) olup yapım maliyetinin verimliliği ile ilgili olduğu düşünülmüştür. Değer ne kadar artarsa net kullanılabilir alanın da o kadar azaldığı ve odanın daha az etkin kullanıldığı sonucuna varılır. İkinci oran, eklenen yapısal alanın net kullanım alanına oranı (R2) olup değişen alnın miktarının değerlendirilmesi amacıyla önerilmiştir. Değer ne kadar artarsa odanın daha az etkin kullanıldığı düşünülür. Son olarak eklenen yapısal alanın toplam yapı alanına oranı (R3) önerilmektedir. Bu oranın yapım maliyeti ve yapısal elemanların yoğunluğunu tanımlayan ve deprem güvenli tasarım için doğrudan etkili olduğu göz önüne alınmış ve ne kadar az bir değer olursa o kadar verimli ve etkin mekanlar tasarlanacağı düşünülmektedir.

Mekanların etkinlik derecelendirmesini göstermek amacıyla dağılım grafikleri geliştirilmiştir. R2 ile R3, R1 ile R3 ve R1 ile R2 değerleri için grafikler sunulmakta ve ortalama değerleri azaldıkça etkinlik seviyelerinin arttığı görülmüştür. Böylece yapısal iyileştirme uygulamasından sonra küçük değişiklikler gözlemlenen mekanların kullanılırlığının fazla olduğu sonucuna varılır. Ancak bu yöntem toplam bina performansını tahmin etmek için olmamaktadır. Yapısal iyileştirme sonrası mekanların kullanılırlığına(etkinliği) göre derecelendirmek için önerilen basit bir yöntemdir.
Oranlar arasındaki ilişki ve tanımlanan etkinlik grupları aralarındaki anlamlı bağlantı tek yönlü varyans analizi (ANOVA) ile incelenmiştir. Etkinlik sınıflarına göre oranlar arasında anlamlı farklılıklar olduğu sonucuna ulaşılmıştır. Etkinlik sınıfları kullanılırlık indexlerine bağlı olmakta ve böylece indeks değeri küçük olan bir mekan için belirli bir etkinlik grubuna ait olduğu söylenebilmektedir. Örneğin, herhangi bir oran için düşük seviyede değerler olması mekanın etkinlik sınıfının da düşük ya da yüksek olmasına bağlıdır. Bu sonuç, dağılım grafikleri ile elde edilen sonuçları destekler niteliktedir.