Circuit Dynamics in a School Facility based on Home-base Area

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Abstract

The latest educational curriculum in Korea started in 1997, and the 'Departmentalized Classroom System', which is a distinguishing modern concept compared with conventional pedagogy, has already been used in several high schools since 2009 and will be expanded to all middle school and high schools by 2014. However, most Korean schools are not yet physically ready to implement the new system. Moreover, despite many trials during the last three years, the characteristic and architectural function of a place called 'Home-base' is still vague and has caused many controversial arguments. In fact, a large number of home-base designs failed to accomplish their original task and there are counter evidences that shows reality was quite different over architect's personal and subjective radical plan. Therefore, this study seeks to introduce and objective scientific method based on an mathematical model of an optimized algorithm for planning a home-base area in a school design. The algorithm developed in this study is designed to determine the most efficient location for a home-base area to minimize the distance students typically need to walk.

1. Research Background and Intention

The Korean educational system is transitioning school education from teacher-centered education through the 'Departmentalized Classroom System.' It has been operating in schools since 2009. This new pedagogy allows students to choose classes based on their academic interest and intellectual level and will be expanded to all middle and high schools by 2014. Unlike the conventional fixed-class system, the Departmentalized Classroom System requires students to change classrooms between classes, which was uncommon in Korea before 1997. This system is commonly used in many Western countries

(i.e., Western Europe and North America), but there has been a constant debate regarding its educational efficiency during the last decade in Korea.

Unfortunately, however, the main essence of this new modernized educational system, the Departmentalized Classroom System, was applied to only 647 Korean middle schools. Among those that adopted the Departmentalized Classroom System, middle schools and high schools combined represent only 12% of 5,267 schools in Korea as of 2010.[1] This is because, first, most Korean schools do not have a sufficient number of classrooms to run this system. Second, schools built before 2000 usually have an I-shape building plan that has a one-sided linear corridor with a spatial array of classrooms, which is the most common conventional layout for fixed classroom education. Moreover, the new spatial concept called

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1) The Ministry of Educational Science and Technology, Korea, 2010.

'Home-base'[2] is unusual from the school administration's point of view and has caused various difficulties with spatial management and arrangement since 2009.

Table 1. Four models of Departmentalized Classroom System in Korea

	Departmentalized Classroom System
Type A	Departmentalized Classroom System for the entire curriculum
Type B1	Departmentalized Classroom System only for Science and Math courses
Type B2	Departmentalized Classroom System only for English courses
Type C	Departmentalized Classroom System based on student's individual academic performance

Nevertheless, there are now four models of the Departmentalized Classroom System, as seen in Table 1. However, these have an irregular form that follows only the minimum pedagogical core requirements suggested by the Korean Ministry of Educational Science and Technology. There are practically no suggested solid standard criteria for operating the Departmentalized Classroom System, and, except Type A, most schools are not able to even provide a space called 'Home-base.' Indeed, if a school is able to ensure a home-base space through building extension, its location and practical usage heavily rely on an architect's subjective decisions based on cost. As one study stated, the mobility issue is the most annoying and dissatisfying factor in the Departmentalized Classroom System education.[3]

2. Hypotheses and Assumptions

The Home-base concept is still vague, though schools have gone through many trials regarding its function. However, since students must adapt themselves to the new educational pedagogy and must shift classrooms within a passing time of 10 minutes after each 50 minute class, this study assumes the shortest distance between a home-base and classrooms as an important variable in planning and educational facility. Therefore, the hypotheses of this study is that well located home-base will positively impact student's overall academic performance and achievement.

3. Research Method

For this study, K High School was chosen to evaluate a practical home-base location based on an algorithm and because it operates the most highly recommended pedagogical program, Type A. Its layout is typical of Korean high schools. There are 28 high schools in Korea that operate under the Type A system as of 2010, but they vary in numbers of students, numbers of classrooms, shape of the building etc. K High School, however, is a relatively new building, which was built before 2000 and is arranged in three separate I-shape buildings that each have a one-sided linear corridor with an array of classrooms, which is the most common shape in Korea before 2000. However, the school was remodeled into a U-shape after attaching and connecting several facilities, including a home-base, in September 2010. This remodel was conducted in order to meet the new pedagogical requirements. a U-shape building plan is now the most common school layout in Korea.[4] Moreover, K High School has a total of 826 students, which is close to the nation's average number of students (851.1 students) per school, with 24 classrooms, which is also very close to the nations's average per high school (24.7 classrooms).[5] Therefore, K High School is an appropriate sample for this research not only from a physical perspective, but also from an educational point of view.

To compose this study, a spatial boundary of K High School was defined, and the current location of the existing home-base location was modified based on an algorithmic analysis that maximizes the practical usage

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5) Korean Educational Development Institute, 2011

of the home-base. This study measured the required daily walking distance using Auto Cad for randomly selected students based on class schedule and compared the existing location and the modified location to minimize student moving distances. This study demonstrates the usefulness of an algorithm for positioning a home-base area in a school design.

4. Home-base and its core variable

The 'Home-base' is a student-oriented stationing area that did not exist in older school designs. One study claims that a home-base is a multi-functional space that allows students to house their school materials and personal belongings between classes and also exists as a resting and/or gathering area during student's recess time. However, there are various strong ongoing debates questioning its educational and functional efficiency in regular school activity, along with concerns about its spatial layout, since the nations just recently revised its educational curriculum with a new pedagogy. As an example, one study categorized the school plan shape into four types and described the home-base with three different spatial models.[6] Other research suggested seven types of general school plans including home-base models[7], while another simply distinguishing among three home-base models, centralized, decentralized and core style.[8] Moreover, a large number of existing studies heavily rely on insufficient surveys or on vague architect's opinions instead of an objective quantitative evaluation. Nevertheless, without indicating which model has the greatest advantage in distance-wise, one model considers

walking distance as an important issue because it may affect circulation patterns due to the characteristics of the home-base. In fact, minimizing the moving distance is obviously just maintaining the basic human behavioral instinct to find the shortest path. Various studies have stressed the short distances as a significant variable in path finding.

A naturalistic observation of a central area in Calgary, Canada by Seneviratne & Morrall[9] claimed that pedestrians chose to use the shortest and straightest rout to their next destination. Similarly, according to Efran & Cheyne[10], pedestrians not only prefer the shortest and the straightest route, but also have a tendency to choose repeated courses that have fewer obstacles. Dean[11] also claimed that even visitors at a gallery exhibition showed a tendency to prefer shorter routes. Domestic studies regarding this matter also determined the shortest route preference as a behaviorally significant pattern.[12] Despite cultural differences between Eastern and Western societies with regard to right or left side walking/turning preferences and sensitivity toward crowd density, choosing the shortest distance to a given destination is a common and universal tendency in pedestrian dynamics. As a consequence, with regard to circulation, empirical studies conducted with naturalistic observation, survey and motion picture analysis since the 1950s have demonstrated that people tend to choose a straight route with the shortest distance to their destination.

On the other hand, a school, along with a home, is obviously the most familiar place for students. According to Park[13], spatial familiarity, homing instinct, distance

6) Seo, B.K & Park, J.Y, A study on the Evaluation of Characteristic for Home-base of Variation Type in High School, Journal of the Korean Institute of Educational Fatalities, 16(4), 2009, pp.71-78
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between classes, corridor width and signage play important roles in any way-finding activity. Therefore, an elaborate objective analysis of the classroom layout including the home-base location is necessary to ensure an enjoyable, convenient educational environment.

5. Mathematical model of the algorithm

The mathematical model and optimized algorithm for this study heavily rely on a facility planning method that was developed in the field of industrial engineering over the past four decades. It is not only a proven method in an academic sense, but also in practice as an objective engineering method for positioning necessary mechanical equipment if required linear order to insure optimized manufacturing production and circulation based on minimum distance and time.[14] To convert the essence of this method and adapt it in architectural terms, Lee et al. developed a mathematical algorithm that considers industrial machinery distribution as analogous to classroom location and the home-base and industrial raw material flow to student circulation.[15]

To construct an architectural algorithm, the first step is to identify the shortest distances between various classrooms, which is indicated as 'Arc', and the number of students per classroom, which is indicated as 'Node'. Afterward, it is possible to find an optimized arrangement to minimize distance traveled, which considers not only the physical distance, but also qualitative conditions such as the width of corridors and crowd movement characteristics.

6. Scope of the analysis

The original design of K high school was planned with three separated I-shaped buildings (Bldg. 1, Bldg. 2 and Bldg. 3) as shown in Table 2.

Table 2. Architectural Conditions of K High School

	School Type: Private School remodeled in 2010
	Number of Students: 826
	Composed with:40 General Classrooms, 8 Epecial Classrooms and 3 Home-base area for each of three floors

In 2010, Bldg. 4 was added between Bldg. 2 and Bldg. 3 and included several classrooms and a home-base area for each floor. The still-separated Bldg.1 is home to the administration offices and four special classrooms. Therefore, to calculate a more reliable location for the home-base area, Bldg.1 was not included in the analysis since it is associated with less student activity. The analysis focused more on Bldg.2 and Bldg.3.

7. Defining node and arc

This study classified and sorted spatial compositional fragments of K High School and identified the number of students (Nodes) for each possible classroom.

Identifying the number of students per classroom is necessary to evaluate the optimized location under the Departmentalized Classroom System. However, since the number of students per classroom varies on a daily basis and per semester, K High School student data
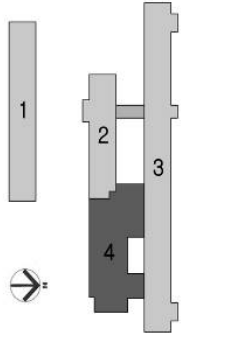
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Table 3. First Floor Spatial Composition and Occupancy

Facility	Occupants
6 Korean Classrooms	204
3 Social Classrooms	102
5 Public Classrooms	170
Pressroom	10
School Infirmary	10
Broadcasting Booth	10
Counseling Center	10

Table 4. Second Floor Spatial Composition and Occupancy

Facility	Occupants
1 Korean Classroom	34
8 Math Classrooms	272
5 Public Classrooms	170
Assistance Office	10
Counseling Center	84
Lecturer Waiting Room	10
Student Lounge	10
Principal's Office	1
Student Council Room	10

Table 5. Third Floor Spatial Composition and Occupancy

Facility	Occupants
6 English Classrooms	204
Language Laboratory	34
Foreign Language Classrooms	34
Science Classroom	34
3 Public Classrooms	102

along with facility planning criteria were referenced. Also, irregular facilities such as bathrooms were not included in order to avoid adding unnecessary students because such facilities are used only on certain occasions. On the other hand, this study considered the maximum number of students per classroom for the most crowded passing time situation.

In addition, the shortest, most direct distance (Arc) between spatial fragments were measured. A crucial amount of academic evidence has emphasized the importance of the shortest distance in a way-finding activity, and the specific meaning of the shortest route in this study is the distance between the center points of two spaces. After every centric point of each space was identified, the shortest distance between spaces was measured as illustrated in Figure 3, and then the
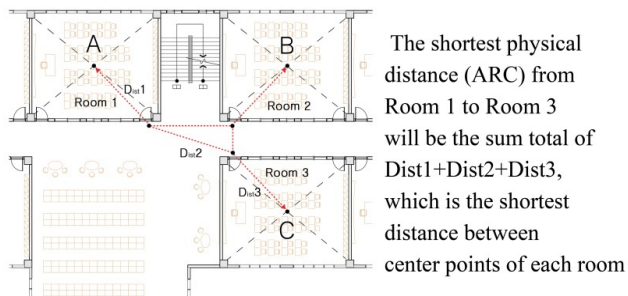

The shortest physical distance (ARC) from Room 1 to Room 3 will be the sum total of Dist1+Dist2+Dist3, which is the shortest distance between center points of each room

Figure 1. Definition fo the Shortest Physical Distance

actual number of students for each classroom was assigned. Thereafter, pattern recognition qualitative variables such as crowd movement dynamics, walking speed, bottle neck phenomena, etc. were taken into account and determined in the adopted algorithm. More specific procedures are presented in the next section.

8. Algorithm analysis and findings

This section will compare the existing home-base and the proposed home-base location, which will be based on the developed algorithm of this study. The mathematical conversion and the notation and para-meters to analyze the K High School are as follows:

w_i indicates the number of occupants in facility and it is shown as $i = 1, 2, ..., N$. Number of total facilities in K High School can be presented as N = (1st Floor)19, (2nd Floor)19 and (3rd Floor)9. Facility type in K High School will be shown as i = (1: Classroom 1-1), (2: Classroom 1-2), (3: Classroom 1-3) .... (16: Pressroom), (17: School Infirmary), (18: Broadcasting Booth), (19: Classroom 1-16). d_{ij} means the distance between facility i and j. Decision variables are as follows:

Y_j : If the home-base is located around facility j, it is indicated as 1. Otherwise it will be 0.

X_{ij} : If students in facility i use a home-base located around facility j, it will be indicated as 1. Otherwise it will be 0.

Parameters, w_i and d_{ij} for the first, second and third floors are given in Table 6, Table 7 and Table 8 respectively. The mathematical model for a certain floor is developed based on the above considerations, and qualitative decisions are determined as follows:

$$\text{Minimize} \sum_{i=1}^{N} \sum_{j=1}^{N} w_i d_{ij} X_{ij}$$

$$\sum_{j=1}^{N} X_{ij} = 1, \ \forall i \quad (1)$$

$$\sum_{j=1}^{N} Y_j = 1 \quad (2)$$

$$\sum_{i=1}^{N} X_{ij} \leq Y_j, \ \forall j \tag{3}$$

$$X_{ij} = \{0,1\}, \ \forall i, j \tag{4}$$

$$Y_j = \{0,1\}, \ \forall j \tag{5}$$

Constraint (1) shows that a home-base needs to be assigned to a certain classroom. Constraint (2) implies that the each floor has one home-base as shown in the current existing plan. Constraint (3) shows that arriving at the home-base area from a ceratin classroom is possible if and only if a home-base is established. Otherwise, if a home-base is not established, then no facility can use the corresponding home-base. Finally, constraints (4) and (5) show that decision variables

Table 6. First Floor: Matrix of occupied spaces and the(ARC)

(Occupants) Facility / Facility (m²)	(34) Class-room 1-1	(34) Class-room 1-2	(34) Class-room 1-3	...	(10) Broad-cast-ing-room	(10) Class-room 1-19
Classroom 1-1 (84m²)		14.1	24.1	...	131.6	145
Classroom 1-2 (84m²)	14.1		14.1	...	121.6	135
Classroom 1-3 (84m²)	24.1	14.1		...	111.6	125
. .	. .	. .	. .		...	...
Broadcasting Booth (84m²)	131.6	121.6	111.6	. . .		18.9
Classroom 1-19 (90m²)	145	135	125	. .	18.9	

Table 7. Second Floor: Matrix of occupied spaces and the(ARC)

(Occupants) Facility / Facility (m²)	(34) Class-room 2-1	(34) Class-room 2-2	...	(1) Prin-cipal's Office	(10) Lec-ture's Waiting Room	(10) Stu-dent Coun-cil Room
Classroom 2-1 (84m²)		14.1	...	72.2	62.2	63.6
Classroom 2-2 (84m²)	14.1		...	62.2	52.2	53.6
. .	. .	. .		...	...	...
Principal's Office (42m²)	24.1	14.1	...		42.5	43.9
Lecture Waiting Room (84m²)	62.2	52.2	. .	14.1		18.1
Student Council Room (90m²)	63.3	53.6	. .	28.1	18.1	

Table 8. Third Floor: Matrix of occupied spaces and the(ARC)

(Occupants) Facility / Facility (m²)	(34) Class-room 3-1	(34) Class-room 3-2	(34) Class-room 3-3	...	(34) Class-room 3-8	(34) Lang-uage Lab.
Classroom 3-1 (84m²)		14.1	24.1	...	83.7	100.6
Classroom 3-2 (84m²)	14.1		14.1	...	73.7	90.6
Classroom 3-3 (84m²)	24.1	14.1		...	63.7	80.6
. .	. .	. .	. .		...	...
Classroom 3-8 (84m²)	83.7	73.7	63.7	. . .		20.9
Language Lab. (126m²)	100.6	90.6	80.6	. .	20.9	

must be 0 or 1. The evaluation was conducted with a computer equipped with Microsoft Visual Studio 2005 C++ and optimization software ILOG CPLEX 11.0. The mathematical process to assign a hone-base location for K high school is shown in Table 6, 7 and 8.

9. Findings

The mean modified plan between the mathematical algorithm analysis and realistic issues such as architectural code, student circulation, connection between facilities, etc. is proposed in Figure 2.

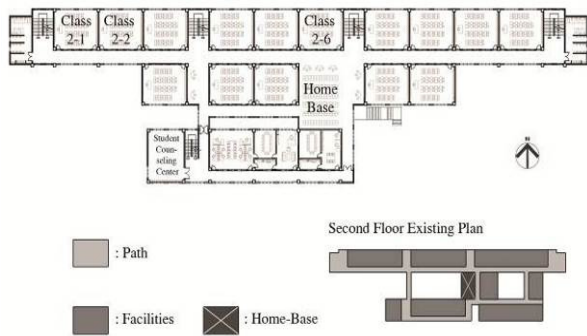Figure 2. Comparison of the Existing Site Plan and the Modifications

Figure 3. Second Floor Modification based on the Mathematical Algorithm
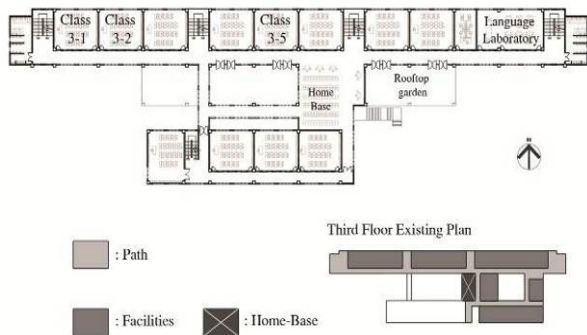

Figure 4. Third Floor Modification based on the Mathematical Algorithm

First, the current home-base locations on the first and second floors have been moved to class numbers in the 1-6 and 2-6 sections, which are also close to the connecting corridor between Bldg.2 and Bldg.3. Based on that suggested new location, a series of new classrooms may be added as shown in Figure 3.

Second, the mathematical analysis also proposed a new location for the home-base on the third floor, which is near classroom 3-5, as illustrated in Figure 4. It also suggested that extended classrooms may be placed around the new home-base location.

10. Discussion and conclusion

To demonstrate its efficiency, three random students were chosen and their travel distances were calculated. The measurement of a randomly selected student's moving distance was based on the actual class schedule of Spring Semester 2012. The measurement assumed that each student will start from their home-base and proceed to their next classroom using the shortest distance. The student will return to the home-base

after their 50 minuted class. However, if and only if a class was scheduled for two consecutive periods in the same classroom, the moving distance was measured only once to represent a realistic situation.

As a result, student A's moving distance is reduced by 13.76% per week (from 1914m to 1650.6m per week, which would be a 263.4m difference and save approximately 1hour 14 minutes per semester). Student B's moving distance has been reduced by 17.43% per week (from 2931m to 2420m per week, which would be a 511m difference and approximately 2 hour 24 minutes saving per semester). In the case of student C, the moving distance has been reduced by 20.69% per week (from 2200.6m to 1745.2m per week, which would be a 455.4m difference and approximately 2 hours 9 minutes savings per semester).

In fact, a passing time of 10 minutes is quite a tight schedule for students to move around after each 50 minute class. In the case of the U.S., some schools allow students to have a 10 to 15 minute recess time twice a day, one in the morning and one in the afternoon, before their additional passing period of 5 to 10 minutes. Consequently, students may have up to a 25 minute break twice a day. Korean students, however, will have to prepare themselves for the next class within 10 minutes.

The proposed mathematical model of an algorithm improved three randomly selected student's moving distances by 17.29% on average. As long as students have less than a 10 minute passing time, 17.29% improvement is believed to have a great and direct impact on overall academic performance and achievement. The mathematical model suggests having the home-base area for the first and second floors located in similar areas since the layouts are the same, but it proposes a different location for the third floor, which is approximately 10 m aside from lower level home-bases. In reality, this would not be acceptable from construction and economic points of view and, therefore, shifting the location of all three new home-bases to the same area on each floor would be more realistic. In other words, manipulation of the mean modified plan is

Figure 5. General behavioral pattern of K High School under the malfunctioning Departmentalized Classroom System

necessary, using a compromised between the results of the quantitative linear analysis and the architect's qualitative decision. This demonstrates that the suggested radical algorithm cannot precisely determine the most appropriate spot based on various qualitative variables and can only suggest particular areas. On the other hand, however, the significance of this study is that the developed algorithm showed valuable potential as a tool in the final planning decision.

In the case of the remodel work for several classrooms and home-base areas of K High School, the home-base area failed to accomplish its original goal. The originally planned home-base facilities are now being used for different purposes, and every classroom has installed an array of lockers in its corridor, which is unlike the expected original extension plan. Consequently, this failure not only made the corridor width narrower, less than 2.5m, which is even smaller than the nations's average school corridor, but also caused greater deviation in moving distance per classroom. In fact, it was witnessed during a field observation on July 17, 2012 that most of the students are not even using their personal lockers but instead carry all their school material in their backpacks, as shown in Figure 5.

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