A Demonstration of BIM-enabled Quantitative Circulation Analysis using BERA Language

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Abstract -

This paper describes a BIM-enabled spatial analysis approach that enables us to compute specific quantitative data using BERA (Building Environment Rule and Analysis) Language and its tool. By comparing design alternatives for an actual building model, this paper also demonstrates building circulation and its associated properties of numeric data. The conventional software-driven approaches have intrinsic limitations that include limited interfaces, restricted parameters, closed rules except pre-defined rules, etc. A script language-based approach, however, is strongly necessary for various and flexible design review tasks especially for retrieving and computing specific dataset. This paper specifically demonstrates actual design review tasks as follows: 1) comparison and visualization of the differences between design alternatives in terms of their different spatial allocations; 2) analyzing numeric data result, NDBC (Numeric Data of Building Circulation), for evaluation of building circulation factors in each department of building; and as a result, 3) overall quantitative analysis and its result will be reported on given actual BIM models in order to support design decision making among various spatial allocation scenarios. For the actual demonstration presented in this paper, we modified some part of BERA language applications and defined appropriate BERA program code and Java code that are executable on given BIM models.

Keywords -

Indoor spatial analysis, automated design review, rule-checking, BERA language, building circulation, Numeric data, NDBC

1 Introduction

Taking advantages of BIM (Building Information Modeling) is becoming common in the AEC-FM (Architecture, Engineering and Construction – Facility Management) field, and the benefits of automated analysis of building design have been reported by several pilot and actual projects [1]. The analysis-purposed dataset from conventional building models usually has intrinsic limitations. They are: 1) not well-organized and mostly arbitrary; 2) qualitative, rather than quantitative; and 3) not objective but mostly subjective. On the contrast, BIM model has been: 1) standardized according to its definition scheme or at least able readily to be converted into the standardized format; and it is 2) able to be assessed the quantity based analysis in a specific design review system. 3) It is possible to automate the process of design quality check objectively. On the basis of BIM-enabled application following this new paradigm, various kinds of automated design review tasks have been developed by several parties including quantitative spatial analysis [2]. Before introduction of BIM paradigm, design evaluation tasks have been performed manually by several domain experts. As a result, it has been cost-ineffective and time-consuming. With BIM, such simulations can be provided through automated interfaces, more quickly and credibly [3]. Also, using BIM before construction in building project introduces automated checking for code compliance and constructability and circulation checking [4]. This design quality analysis is commonly implemented in GUI (Graphical User Interfaces)-based software, however, those conventional software-driven approaches have intrinsic limitations that include limited interfaces, restricted in the way of control complex and complicated parameters, defining rule-checking code, etc. [5]. Software-driven approach to the rule-checking is based on pre-defined rules and it is effective only within the boundary of such rules. This usually hinders the flexibility of the rule definition. To the contrary, script language-based design review approach is able to resolve most part of those limitations. BERA (Building Environment Rule and Analysis) Language [6] is one of the language-driven methods for analyzing indoor spatial program and building circulation. BERA Language and its tools are capable of making quantitative results through its flexibility such as user-defined rule checking code. Especially in building remodeling project, language-driven approach can significantly contribute to compare and analyze various design alternatives focusing on spatial program and building circulation. Therefore, this paper aims to demonstrate a BIM-enabled quantitative spatial analysis using BERA Language and its tools based on an actual building remodeling project. We can analyze specific issues of the results regarding building circulation quantitatively through returned numeric data from execution of specific BERA Language program code.

2 Research Scope and Objective

The scope of this study is about BIM-based indoor spatial quantitative analysis in the way of language-driven approach specifically using BERA Language. Another focus is on introducing and demonstrating NDBC (Numeric Data of Building Circulation), as numeric dataset from various properties of building circulation. We can apply the value of NDBC as quantitative design analysis to compare different design alternatives in actual remodeling project. The NDBC values can be a quantitative determinant to aid which design alternative would be selected.

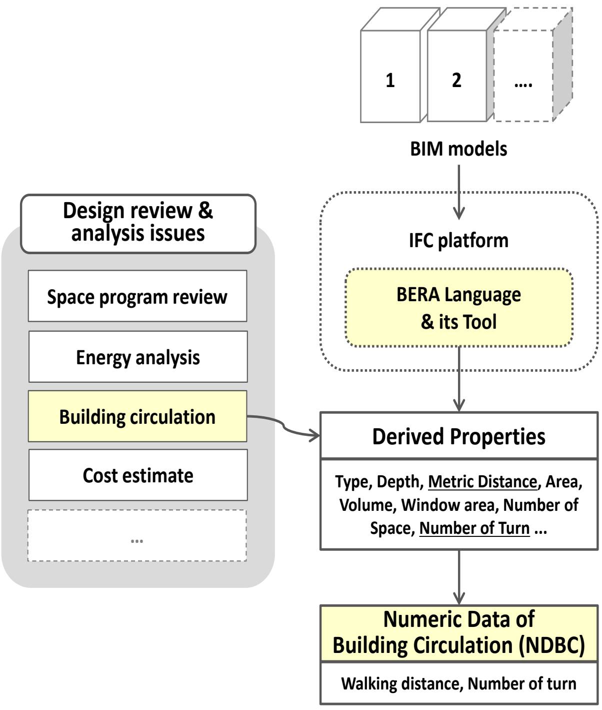


Figure 1. Overview of the proposed approach to the BIM-enabled quantitative spatial analysis

The execution platform of BERA Language and its tools is Solibri Model Checker (SMC) [7], and the building model is in IFC (Industry foundation Classes) format exported from Autodesk Revit. As shown in Figure 1, we survey the quantitative data and properties of spatial analysis, and then we plan to demonstrate building circulation analysis using BIM models based on derived circulation-specific properties.

3 Approaches

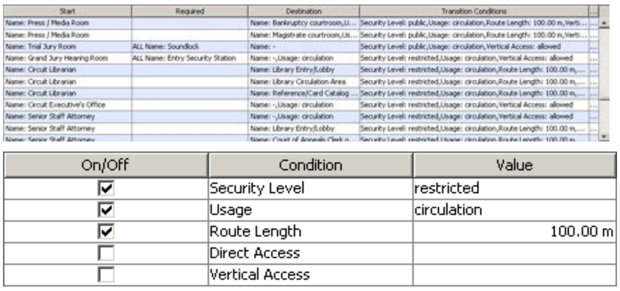
3.1 BIM-enabled quantitative spatial analysis

BIM-enabled design review projects have been conducted by several challengers especially for generating spatial program review reports. The report represents the given building model's space program in an architect-friendly form; for example, number of spaces, gross area, usable area, building efficiency and so on [8]. Before introduction of BIM, design evaluation was performed manually by multiple domain experts and was time consuming and expensive. However, report of spatial analysis such as indoor circulation properties and spatial program can be provided through automated interfaces, more quickly and quantitatively with BIM technique [9]. In the case of GSA (General Services Administration) project for courthouse in US 2007 [2, 10], the purpose of validating a spatial program using BIM is to efficiently and accurately assess design performance, relative to GSA space program requirements. They partnered with Georgia Tech and Solibri on their circulation validation efforts. Georgia Tech research team had implemented automatic circulation analysis and security checking in the conceptual design phase of the US Courthouses. They used SMC platform and IFC from BIM architectural design tools [11]. By using BIM models, GSA could automate the spatial validation process to ensure that all designs in the final concept phase accord to the spatial requirements [10]. Therefore, the automation of analysis process could save the time and improve accuracy of the results about security issue [2, 12].

3.2 Limitations of Software-driven approach

The software-driven method, as the previous way for rule checking, is a general technique in the BIM domain area. For various purpose of automated design quality analysis, some kinds of BIM-based software based on GUI has been developing and being used. However, software tools that allow for a sophisticated and complex spatial analysis of building models are not yet available effectively [13]. The software-driven approach has not been flexible in its application and expandability due to its pre-defined rules, limited interaction, parameter-driven approach, etc., specifically in controlling complicated rule parameters.

As shown in Figure 2, only pre-defined parameters are available in actual design review tasks. The process of problem solving for developing new functionalities is cost and time-consuming. Therefore, it is necessary to develop the method which is easy-to-use for novice users to develop and facilitate rule-checking methods.



Start	Required	Destination	Transition Conditions	...
Name: Press / Media Room		Name: Bankruptcy courtroom,U...	Security Level: public,Usage: circulation,Route Length: 100.00 m,Verti...	...
Name: Press / Media Room		Name: Magistrate courtroom,Us...	Security Level: public,Usage: circulation,Route Length: 100.00 m,Verti...	...
Name: Trial Jury Room	ALL Name: Soundlock	Name: -	Security Level: public,Usage: circulation,Vertical Access: allowed	...
Name: Grand Jury Hearing Room	ALL Name: Entry Security Station	Name: -,Usage: circulation	Security Level: restricted,Usage: circulation,Vertical Access: allowed	...
Name: Circuit Librarian		Name: Library Entry/Lobby	Security Level: restricted,Usage: circulation,Route Length: 100.00 m,...	...
Name: Circuit Librarian		Name: Library Circulation Area	Security Level: restricted,Usage: circulation,Route Length: 100.00 m,...	...
Name: Circuit Librarian		Name: Reference/Card Catalog ...	Security Level: restricted,Usage: circulation,Route Length: 100.00 m,...	...
Name: Circuit Executive's Office		Name: -,Usage: circulation	Security Level: restricted,Usage: circulation,Vertical Access: allowed	...
Name: Senior Staff Attorney		Name: -,Usage: circulation	Security Level: restricted,Usage: circulation,Vertical Access: allowed	...
Name: Senior Staff Attorney		Name: Library Entry/Lobby	Security Level: restricted,Usage: circulation,Route Length: 100.00 m,...	...

On/Off	Condition	Value
☑	Security Level	restricted
☑	Usage	circulation
☑	Route Length	100.00 m
☐	Direct Access	
☐	Vertical Access	

Figure 2. An example of BIM software-driven approach to the design analysis: only pre-defined parameters in a table regulate specific design rules such as security or distance conditions. [6]

3.3 A script Language-driven approach and BERA Language

One of the countermeasures for limitations of software-driven method, language-driven approach has been introduced for resolving these problems. There is BERA (Building Environment Rule and Analysis) language [6] as a script language-driven method. It aims to analyze the building environment as its literal meaning, so that it doesn't produce or modify building object model. BERA has strength in interactive automated review, user-driven rules and analysis, various execution tools in syntactic and semantic way.

On these concepts of BERA, there are 3 main points 1) it is domain-specific so that used in experts' stand in AEC field; 2) it is based on programming language; 3) it uses meaningful symbol marks such as =, <, >, as Rule language. Using script language which deals with space objects and those properties relations belonged in IFC format model, users can analyze or compare the data they want to get for results and simulation in quantitative way. Since the BERA Language supports various commands for complex design guide, users can implement rule-checking at specific part intuitively. The approach such as BERA which is using scripts language enables to check rules in the flexible and effective way [6].

4 Quantitative Data of a Circulation Path and definition of NDBC

4.1 Quantitative data of a circulation path

The purpose of this paper is especially focusing on analyzing the spatial circulation properties that could not be checked specifically by customized definition in previous way such as software-driven method. A fundamental issue in building circulation is specific path people take when moving from some spaces to another [9]. People using or occupying the indoor space of building usually evaluate the efficiency of space qualitatively. On the issue of Building circulation, there have not been exist numeric data reports from the way of design analysis. The analysis of spatial circulation in rule-based systems assists users to define and apply customized rules that check conditions of the building by executing on a given model and returned reports [14, 15]. BERA Language as a rule-based script language is used in this demonstration and it is able to convert qualitative contents to quantitative visualized report data. The following BERA code is an example about get Path (Lobby to Room) in building spatial program and there are its returned data properties from BERA program code. Figure 3 is a process chart getting returned quantitative data using BERA code.

```
Path p = getPath("Lobby", "Room");
get(p);
```

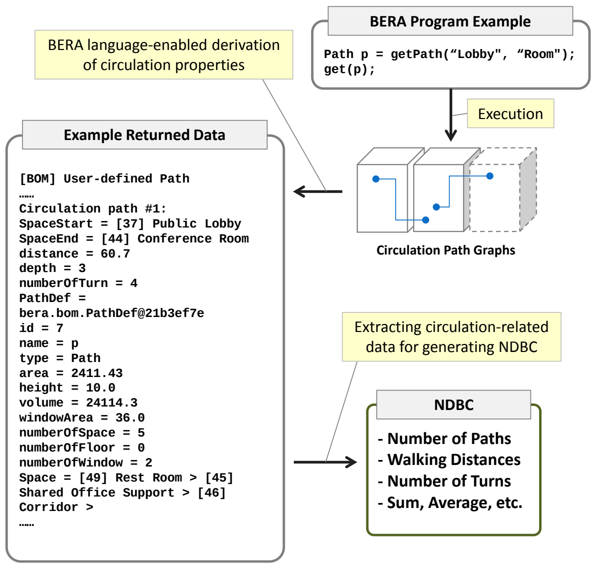


Figure 3. An example of property data set from the circulation path between 'Lobby' and 'Room'

Each returned properties of paths have numeric data regarding user defined BERA code. The returned data contains the property of area, height, volume, window area, number of space, number of window and so on, so that user can apply those results regarding to their specific purpose of design analysis. Figure 4 shows a visualized circulation graph from user-defined method mentioned as below using IFC test model.

```
Path p = getPath("Lobby", "Department");
get(p);
```

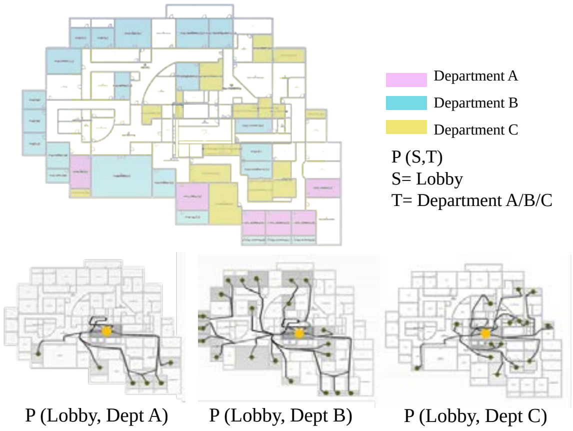


Figure 4. Visualized path graph on the test model using BERA code

Figure 4 describes the all of possible circulation paths and those properties from the path of Lobby to each department A, B, and C. The result shown as Figure 4 was not possible in previous rule-checking software-driven approach. However, the study about whether those numeric information data contains extended meaning or not is out of scope in this paper. BERA and its application only produce and suggest the numeric data in quantitative way.

4.2 Definition of NDBC (Numeric Data of Building Circulation)

NDBC (Numeric Data of Building Circulation) is a quantitative building circulation properties data using language-driven approach. In this section, we provide a formal definition of NDBC derived from returned data of building circulation using BERA language and its application. As shown in Figure 3, data of number of Paths, walking distances, number of turns and summation of distances and number of turns) extracted from returned report would be NDBC. NDBC especially based on BERA Language and JAVA code that is able to calculate various and complex properties of circulation what users require for specific issues in building model. There are some meaningful formulas of NDBC as following below.

1. (n)P (S, T)

Where S is start space and T is target space, and (n)P is the number of Path instances.

$$S = \{si \mid 1 \leq i \leq n;\ n = \text{number of start spaces}\} \quad (1)$$
$$T = \{ti \mid 1 \leq i \leq n;\ n = \text{number of target spaces}\} \quad (2)$$
$$P\,(S, T) = \{pi \mid 1 \leq i \leq n;\ n = \text{number of paths}\} \quad (3)$$
$$(n)P\,(S, T) = (n)S \bullet (n)T \quad (4)$$

P denotes a set of number of building circulation paths, S is a set of start space objects and T is a set of target space objects of building. As noticed above, start space and target space should be defined to get number of path. If there are sets of S = {(s1), (s2)} → (n)S = 2 and T = {(t1), (t2), (t3)} → (n)T = 3, then set P can be derived as P (S, T) = {(s1, t1), (s1, t2), (s1, t3), (s2, t1), (s2, t2), (s2, t3)} → (n)P (S, T) = 6.

2. SW (P(S, T))

Where SW is the summation of total path walking distances of Path set P

$$SW\,(P(S, T)) = \{W1 + W2 + W3 + \ldots + Wn\} = \sum_{n=1}^{P} W\,n \quad (5)$$

W denotes walking distance from start space S to target space objects T. Because the each walking distance is according to the number of start and target spaces and the number of paths, analyzing comparable data of walking distance is able to be miscalculated. However, the summation of walking distance data can be compared per each different kinds of target space object.

3. ST (P(S, T))

Where ST is the summation of total number of turns of Path set P

$$ST\,(P(S, T)) = \{T1 + T2 + T3 + \ldots + Tn\} = \sum_{n=1}^{P} T\,n \quad (6)$$

The number of turns in circulation is also significant issue in building circulation analysis. The summation of number of turns connotes that how many times people should turn their path while going to target space from start space.

4. ASW (P(S, T))

Where A is average of the summation of total walking space per the number of path

$$ASW\,(P(S,T)) = SW\,(P(S,T))\,/\,(n)P\,(S,T) \qquad (7)$$

The summation of total walking distance has each different value according to target spaces and those numbers. When analyzing the walking distance equally, there should be average walking distance value per the number of path of its target spaces.

5. AST (P(S, T))

Where A is average of the summation of total number of turns per the number of path

$$AST\,(P(S,T)) = ST\,(P(S,T))\,/\,(n)P\,(S,T) \qquad (8)$$

The summation of turn of numbers of paths also should have its average value per paths to analyze with other kinds of paths.

5 Demonstration

5.1 Application of indoor spatial analysis with NDBC

This section demonstrates a visualization of NDBC for a specific spatial program and circulation generated by BERA language and its tool. The graph of circulation path is the way of visualization and it can show not only the visualized graph but also prehensible and approximative value of walking distance or number of turn in path. Figure 5 is an example of visualized path graph in one floor of test IFC model using BERA language in SMC and rule set code. s1 is start space "Hall 4" and t1 to t12 are target spaces include "Interior" nomination. The paths from s1 to each t1 to t12 are noticed as p 1 to p12. Following code below is BERA rule-set used.

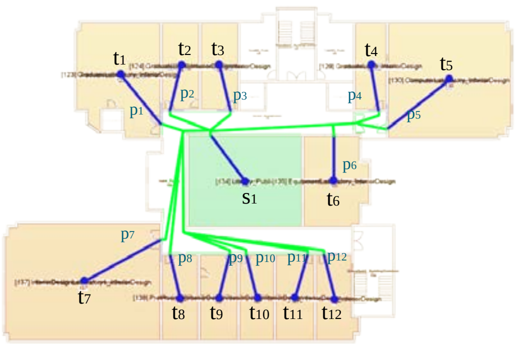


Figure 5. An example visualization of NDBC on top of given test IFC model.

```
Space aa {
  Space.Floor.number = 5;
  Space.name = "Hall4"
}
Space bb {
  Space.Floor.number = 5;
  Space.name = "Interior"
}
Path p = getPath(aa, bb);
get(p);
```

Through NDBC definition, we can analyze circulation path in Figure 5 as following,

S = {s1}
T = {t1, t2, … t12}
P (S, T) = {p1, p2, … p12},
(n)P (S, T) = (n)S • (n)T = 12
SW (P(S, T)) = 488.9
ST (P(S, T)) = 20
ASW (P(S, T)) = 40.74
AST (P(S, T)) = 1.6

In the visualization of NDBC as shown in figure 5, one floor area that has one start space and 12 target spaces included in one department, we can figure how many paths from start space to target space and following data properties such as SW (P(S, T)) , ST (P(S, T)), ASW, AST. These numeric data have differentiated method from previous rule-checking software by language-driven approach and quantitative results. This study is focusing on circulation and paths and those numeric data value, however, the application of language driven design analysis can be expanded to other issue of building design not only in domain of circulation.

5.2 Demonstration of actual remodeling project apply to NDBC

We utilized NDBC for evaluating an actual building remodeling project to compare design quantitatively between before and after design, located in Seoul, Korea. Hanyang University Human ecology building in Seoul, Korea had been remodeled since in December, 2012 and it was completed in March, 2013. There are 3 departments according to majors (Food and Nutrition, Clothing and Textile, and Interior design) in this building. Design analysis about spatial relocation should be considered whether reasonable, efficient and impartial or not. Therefore, design alternatives of remodeling project should be analyzed and compared with previous design in a quantitative way. This approach generates an objective outcome such as space quality review reports. To prevent waste of time and expense, design quantitative evaluation is required in preconstruction stage. Through objective and numerical report of design review, the appropriate design can be selected among other design alternatives according to purpose of design.

Figure 6. An actual test case model demonstrated in this paper: a college building of Hanyang University, Seoul, Korea

Figure 7 shows spatial allocation alternatives according to 3 major departments in this building. In the view of the remodeling project, outer wall structure is not changed while department allocation has changed.

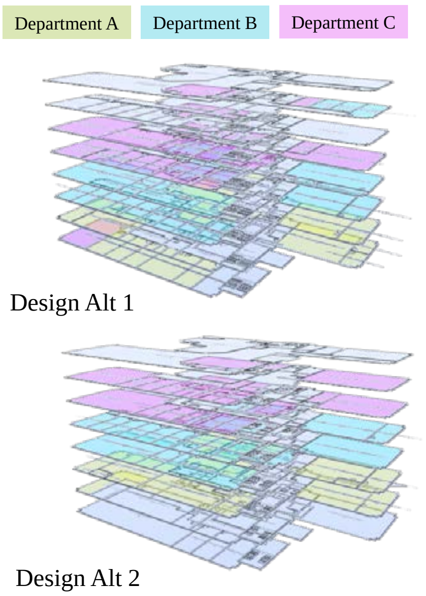


Figure 7. Planning the allocation of three different departments for the actual model.

The changed relocation of design alternative 1 and 2 is focusing on the spaces related to 3 majors in this building. For example, the classes among the same major should be located within a range at least 2 floors so that user can save unnecessary walking distance. Based on the above plans shown as figure 7, we apply example of same BERA code and JAVA to analyze NDBC value for circulation of alternative 1 and 2. Figure 8 describes the execution circulation analysis on the scope of the department 'A' through prepared IFC models for design 1 and 2 and Solibri Model Checker as IFC platform. The collaboration code of BERA and JAVA below is used for execution of circulation analysis, NDBC.

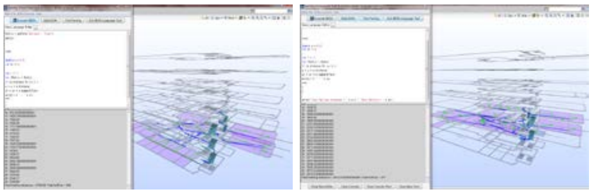


Figure 8. Execution of department A circulation analysis in design alternative 1(left) and 2 (right) using BERA Language and SMC

```
Path p = getPath("Entrance", "Food");
get(p);

java;
double s = 0.0;
int st = 0;

int i = 1;
for (Path p : Path){
  if (p.distance != null) {
    s = s + p.distance;
    st = st + p.numberOfTurn;
    print(i + " : " + s);
    ++i;
  }
}
```

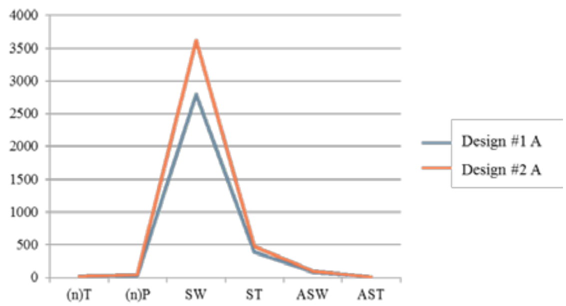
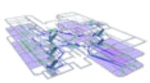
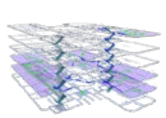
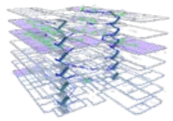
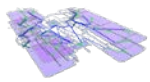
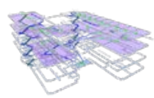
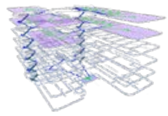


Figure 9. Chart of NDBC result of department A in department 1 and 2.

We can analyze the circulation path and also compare NDBC as showed in Figure 9. The chart shows each data value of number of target spaces, number of path, summation of walking distance, summation number of turn, and average of SW and ST. The overall graph flow in comparison chart, Design #2 is above design 1 for each parts of NDBC contents. Department A has two more target spaces in design 2 than 1, ASW and AST value that is about numeric value per each path of design 2 is also higher than 1. Table 1 is the NDBC results of all major department spaces and circulation properties using BERA rule-set.

Table 1. Comparison between two design alternatives using spatial quantity data enabled by BERA language and its tool.

Design	Alt #1			Alt #2		
Path						
P_Start	Entrance 1， 2	Entrance 1， 2	Entrance 1， 2	Entrance 1, 2	Entrance 1， 2	Entrance 1， 2
P_Target	Dept A	Dept B	Dept C	Dept A	Dept B	Dept C
Floor Level	B1, Level 1, Level 2	Level 2, Level 3, Level 6	Level 4, Level 5, Level 6	Level 1, Level 2	Level 3, Level 4	Level 5, Level 6
Area	9570.67	12987.43	190554.73	10164.96	12672.64	13050.5

Design	Department	(*n*)T	(*n*)P	SW	ST	ASW	AST	Total ASW	Total AST
Alt #1	A	17	34	2790.89	389	82.08	11.44	400.12	90.60
	B	25	50	6533.59	1436	130.67	28.72		
	C	27	54	10118.21	2724	187.37	50.44		
Alt #2	A	19	38	3614.21	477	95.11	12.55	496.33	115.10
	B	23	46	7495.24	1782	162.94	38.73		
	C	23	46	10960.97	2936	238.28	63.82		

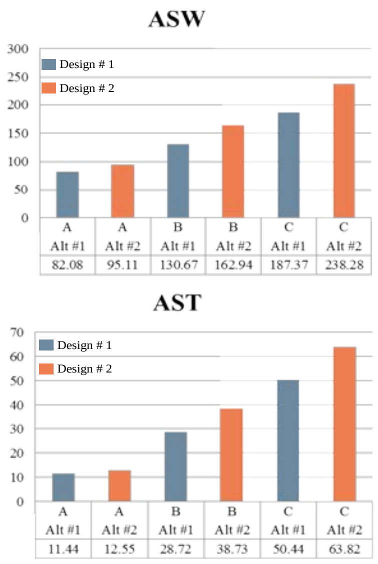


Figure 10. Data Chart of ASW and AST for the comparison between design alternatives

We can get NDBC of circulation path properties respectively as shown in Table 1. Each design plan has different number and area of relevant spaces, so that there is difficulty for comparing between design alternatives with total summation of circulation path data. Therefore, ASW and AST are influential factors for comparing overall design alternatives irrespective of contained the number of spaces. Figure 10 is the chart of comparison ASW and AST regarding to each design alternatives #1 and #2. Both ASW and AST value in design #2 are higher than design #1 and it means that circulation path from entrance to spaces of three different departments in design #2 has longer walking distance and more number of turn than those of design #1.

6 Summary

In this paper, we proposed and demonstrated a quantitative analysis approach to the comparison between design alternatives using NDBC, as we introduced the abbreviation of the term Numeric Data of Building Circulation. This paper surveys and demonstrates that script language–driven design analysis has necessity and efficiency compared to previous software-driven approach through BERA Language. There is script language between accessibility and usability of software and sophistication and applicability of programming language. The script language-driven design analysis enables: 1) accurate query of target building object, 2) flexibility of re-defining rule set regarding the complex building design quality, and 3) reporting about implementation of design analysis and its result. Based on those issues, we defined NDBC that quantitative returned data from BERA language and its tool and demonstrated actual remodeling project case. It is possible to suggest objective value of building circulation for helping to choose most efficient design among the other design alternatives. This study focuses on building circulation centrally from among the various building design issues, however, its expendability and applicability can be able to affect succeeding study of quantitative design analysis.

Acknowledgment

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