Development of the Scenario-based Evaluation of Indoor Circulation using BIM-enabled Parameters

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Abstract –

This paper aims to develop the scenario-based analysis of indoor circulation using BIM-enabled parameterized quantities of a circulation path computed by BIM-enabled applications such as walking distance, spatial topology, number of turns, etc. A building circulation plays an important factor to plan overall spatial configuration based on specific purposes so that it has been one of priorities even in the beginning of the design. As supported by Building Information Modeling (BIM) and its applications, a design review process has been conducted more efficiently and accurately by using computed quantitative circulation-related data, compared to the conventional process performed in manual. However, qualitative factors of building circulation such as efficient route have been excluded practically as a target of the BIM-based design evaluation.

As motivated by such fundamentals, precedent research discusses design evaluation approach in a BIM environment focusing on qualitative circulation issues such as 'convenient access to a specific space'. Based on the research, this paper develop the scenario based evaluation framework in terms of a generalization of the evaluation process. Furthermore, the framework is demonstrated using a test model with specific scenario and circulation evaluation-purposed application implemented by the authors.

Keywords –

Building Information Modeling (BIM); Indoor circulation; Scenario-based evaluation; Parameterization

1 Background

As supported by Building Information Modeling (BIM), design review process has been conducted more efficiently and accurately by using rich building information compared to the conventional process performed in manual [1, 2]. The BIM-enabled applications have computed series of explicit quantity data, especially for indoor circulation such as metric distance, number of turns, spatial depth, etc [3, 4, 5]. This enables us to measure the explicit egress distance between specific spaces and exits, and establish quantitative indicators based on those data in order to review various requirements and support design decision [3, 6, 7].

In terms of BIM application for indoor circulation analysis, there have been various approaches, including circulation graph representation, rule compliance checking, domain-specific language development for reviewing rules, circulation related data application for design review and so on. Lee, J. K. et al. [6] defined a computational method named as universal circulation network (UCN) to measure explicit walking distance and visualize the circulation path using geometry and spatial topology on a given BIM model. The UCN is implemented as specific software to review circulation-related rules and has been utilized for practical use. Lee, J. M. [8] represented logical, automated checking process of circulation associated rules considering various design development stage from preliminary concept design to the final concept design stage. In addition, the generic method was applied to develop related application system and validated by applying actual courthouse models. As BIM domain-specific programming language, the Building Environment Rule and Analysis (BERA) was implemented for the purpose of review of building model focusing on spatial program and building circulation analysis [3, 9]. With using BERA language, varied building objects including spaces and paths with their properties can be handled by user-defined query. Its applications have presented its utility to enable users to define customized rule and review circulation design based on the user-defined rules. Lee, H. et al. [5, 10] utilized BERA language to derive useful circulation property data and calculated results achieved from BIM models so as to analyze design alternatives of actual remodeling building. Lee, Y. C. et al. [11] extended BERA language for checking accessibility and visibility conditions of spatial requirements. The algorithm for checking accessibility and visibility analyzes the number of turns to reach the end point from the start point. Lee, H. [12] established path object with its related properties and expanded properties which is called as Numeric Data of Building Circulation (NDBC). The path objects with its properties are defined as a BIM-enabled and building-oriented approach in order to resolve building circulation issues.

Current BIM-enabled design analysis and evaluation approaches have handled circulation factors partially that are expressed in explicit way using as-is data. In other words, qualitative factors such as efficient or accessible route have been excluded practically as a target of the BIM-based design evaluation [4, 13]. However, large portion of circulation design requirements described in the RFP or design guidelines (except for building regulatory codes) consist of qualitative factors rather than explicitly-defined ones and those factors influence pedestrian circulation quality from various perspectives [13, 15]. As motivated by such fundamentals, precedent research [14] discussed design evaluation approach in the BIM environment focusing on qualitative circulation issues. To develop a circulation evaluation approach, following strategies was introduced; 1) As-is data derived from BIM model is fundamental sources for definition of evaluation factors. 2) Those data are weighted in accordance with their relative priorities considering design intention.

This paper extends and demonstrates the proposed circulation evaluation framework in terms of a generalization of the evaluation process. In addition, related application is implemented for applying the framework easily by users.

2 Research objective and scope

This research aims to deal with BIM-based approach to circulation evaluation considering qualitative circulation factors. With its objective the scope and process of the research are summarized as follows.

1. Representation of qualitative circulation factors with quantitative data: This part is to summarize developed classification and definition of circulation quality-associated factors that were tackled in precedent research [14]. Those factors are represented with related circulation quantities derived from BIM models.
2. Development of a circulation evaluation framework: The suggested framework is based on the parameterized circulation data that define circulation factors. The framework is composed of three parts and results in final calculated value which is called as PPV (Parameterized Path Value).
3. Implementation of circulation evaluation application: External database and its application software were implemented for demonstration purpose. Using the application circulation evaluation framework can be easily managed.
4. Demonstration of circulation evaluation using the application: In order to verify applicability of the suggested framework case study was conducted by using conceptual office model based on a specific scenario and the implemented application.

3 Representation of Indoor Circulation factors with Quantity Data

In order to define circulation evaluation factors, this paper mainly focuses on BIM-enabled circulation related quantities that have been recognized as quantitative and objective grounds for analyzing circulation design[3, 5, 7, 10, 11, 12, 13, 16]. The scope of circulation factors is defined referring to previous studies in circulation-related design aspects from a pedestrian point of view [16, 17, 18, 19, 20, 21, 22, 23, 24]. They are categorized into 4 types and each factor type is composed of two or three circulation-related quantity data.

3.1 Relative Distance

One of the most effective and fundamental evaluation methods of pedestrian circulation is generally based on metric distance. In general, vertical circulation paths increase burden to move rather than horizontal circulation from the perspective of pedestrians. Especially for people with physical disabilities, circulation with less vertical distance rather than circulation with short distance can be a serious issue. In this regard, relative distance composed of horizontal and vertical distance is a main circulation factor depending on design purposes, etc.

The first type of circulation factors and its related BIM quantities are defined as:

$$D_i = \{VD_i, HD_i\} \tag{1}$$

Where D_i connotes relative distance of P_i, ith path and VD, HD are vertical distance and horizontal distance each.

3.2 Accessibility of Circulation path

As quantitative measures for assessing the accessibility of circulation, condition of intermediate spaces regarding connectivity is focused in this paper. There is two representation way in this paper; the number of intermediate spaces between start and end spaces and directly accessible spaces to those spaces. In terms of planning circulation with easy access, the number of intermediate spaces has a negative effect on accessibility and the (average) number of directly accessible space of intermediate space, however, would have a positive effect.

The second type of circulation factors and its related BIM quantities are defined as:

$$A_i = \{IS_i, AS_i\} \quad (2)$$

Where A_{ccess} connotes accessibility of P_i, ith path and IS, AS are the number of intermediate spaces and the average number of directly-accessible spaces in order.

3.3 Simplicity of Circulation path

Influence of circulation pattern has been acknowledged through several researches such as those in the domain of space syntax [21, 23, 24]. Accepting the idea of turning conditions which derive circulation pattern, simplicity of circulation is represented with two elements; the number of turns and the angle of each turn

There are three path objects, path A, B and C instantiated after assigning start and end spaces as described in Figure 1. They each feature different turning conditions;1) path A has no turn, 2) path B has a turn with a small degree of variation and 3) path C has a turn with a large degree of variation. When the three paths have same metric distance, path A is regarded as the most simple and easy path among them and followed by path B.

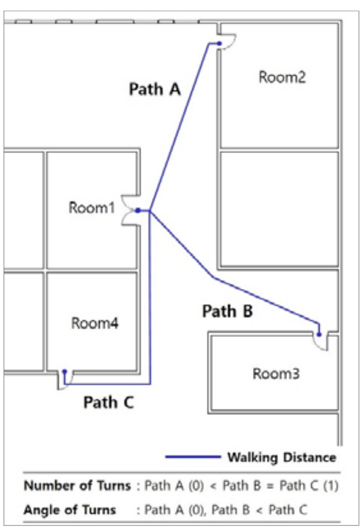

Figure 1. Example of two kinds of BIM data related to clarity of the path; the number of turns and angle of each turn

In this regard, the third type of circulation factors and its related BIM quantities are defined as:

$$C_i = \{NT_i, AT_i\} \quad (3)$$

Where C_i connotes simplicity of circulation of P_i, ith path and NT, AT are the number of turn and the angle of turn in order.

3.4 Pedestrian friendly path environment

Among the various circulation factors for pedestrians, path environment such as sunlight exposure, spatial scale and surrounding scenery can affect people in building physiologically or physically [12, 17, 18, 19]. In this paper, circulation factor regarding pedestrian friendly path environment has 3 scenarios; 1) window area, 2) passing space volume, 3) ratio of specific space usage such as public spaces and recreational spaces.

The Figure 2 shows two alternatives, path A and path B, which have same start space (Room1) and end space (Room2). Even though path A has short metric distance and no turn, path B is preferable when taking into account comfortable and spacious circulation space with little traffic.

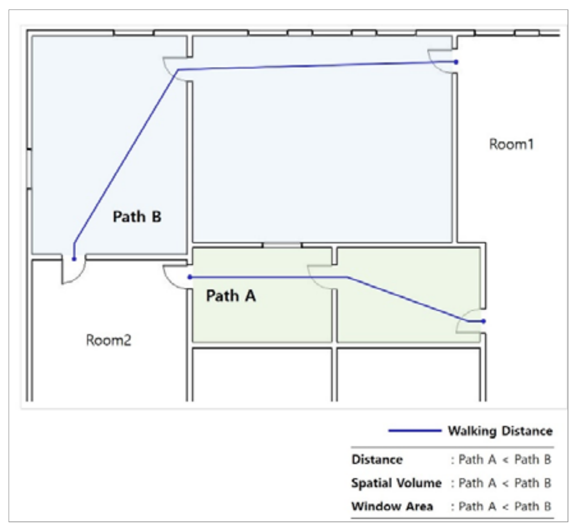

Figure 2. Example of three kinds of BIM data related with pedestrian friendly path; window area, spatial volume, ratio of space usage

The fourth type of circulation factors and its related BIM quantities are defined as:

$$U_i = \{WA_i, VM_i, UG_i\} \quad (4)$$

Where U_i connotes pedestrian friendly path environment of P_i, ith path and WA, VM, UG are window area, spatial volume and ratio of specific space usage in order.

4 BIM-enabled Circulation Evaluation Framework using Parameterized Quantitative Data

4.1 Path generation

The BIM-enabled evaluation process begins with path generation from a BIM model. Unlike static building models such as space object and structural object, path object is dynamically generated by two types of spaces which are the start and end space. Therefore, definition of start and end space (at least one of each) is prerequisite for generating paths in BIM environment. After creating path objects, circulation related quantitative data introduced in the previous section can be obtained from circulation graph-driven path properties such as metric distance and turn-related properties and spatial or architectural object properties which is related the path objects.

4.2 Parameterization of Circulation Data

The driven quantitative data representing four types of pedestrian circulation factors are raw data that play a role of objective source to compare design alternatives and can be used for various applications. In this paper, parameterized circulation data are suggested for design evaluation as application of circulation-related quantitative data. The parameterized circulation data have several concepts as follows.

1. The quantitative circulation data with different unit of measure can be compared after standardization process. When standardizing them, circulation data can be distinguished between positive factors and negative factors of circulation quality.
2. Weighting function has two types including weighting each circulation data within a specific factor and weighting among circulation factors.
3. Weight ($W(X)$, $W(PF)$) implies a relative degree of importance of each factor and total weights is 1 (100%).
4. Weighting of circulation factors depends on users who determine two types of weights individually.
5. The result value (PPV) which is calculated from the circulation data and their assigned weights is the representative value of the individual path object for evaluation.

4.3 Derivation of Parameterized Path Value

On the basis of definition of circulation factors, their component (quantitative data) and two types of weight, parameterized path value derivation process is summarized as follows. The final result value is called as PPV(Parameterized Path Value) and it implies that the path with higher PPV indicates highly evaluated path than others.

- **Definition 1. - 5.**

1. $P = \{P_i | P_i$ is derived path objects from a building model, $i \leq n; n$ is the number of path objects }
2. $PF_i = \{PF_i \mid PF_i$ is a circulation factor of path $Pi\}$ $= \{D_i, A_i, C_i, U_i\}$
3. $X_i = \{X_i \mid X_i$ is quantitative data consisting of $PF_i\}$ $= \{VD_i, HD_i, IS_i, AS_i, NT_i, AT_i, WA_i, VM_i, UG_i\}$
4. $W_X = \{W(X_i) \mid W(X_i)$ is a weight given to X_i, $0 \leq W(X_i) \leq 1\}$
5. $W_{PF} = \{W(PF_i) \mid W(PF_i)$ is a weight of PF_i, $0 \leq W(W_{PF}) \leq 1\}$

- **Process 1.** Standardization of the circulation data [25]

(Positive Factor)

$$(S(X_i)) = \frac{X_i - Xmin}{Xmax - Xmin}$$

(Negative Factor)

$$(S(X_i)) = \frac{Xmax - X_i}{Xmax - Xmin}$$

X_{min}, X_{max} : Minimum/ maximum value among overall path objects

- **Process 2.** Parameterization of path data

$Prm(PF_i) = \Sigma\, S(X_i) \cdot W(X_i)$

- **Process 3.** Derivation of PPV

$PPV_i = 1000 \cdot \Sigma\, Prm(PF_i) \cdot W(PF_i)$

5 Implementation of Circulation Evaluation Application

For demonstration of suggested circulation evaluation an external database and application that is connected with database sources are implemented. This application is developed to support scenario-based circulation evaluation with consideration for priority of circulation factor. With the application, user can 1) review the overall path objects and their quantitative data needed for evaluation, 2) set user-defined weights of each circulation factors considering the purpose of design, and 3) evaluate the target paths based on PPV analysis. Figure

3 represents examples of user interface for controlling weight.

In order to support its functions, the application is operated based on an external database of overall circulation quantity data computed by BIM-enabled calculators in advance. Based on the circulation data established in the database, weights assigned to each circulation data and factor are determined by users. Applying user-defined weights with the circulation data that is the process of parameterization of circulation data, calculation for the PPV is done in the back end side of the software. Figure 4 describes the link between the external database for the model information and the application.

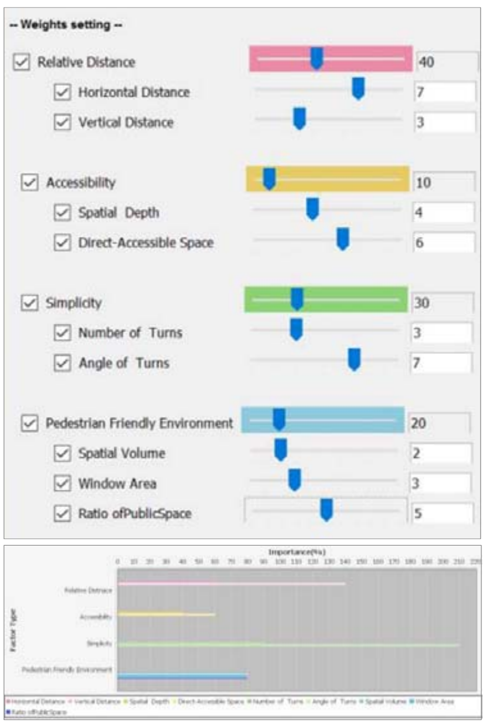

Figure 3. Examples of user interface for controlling weights of the application

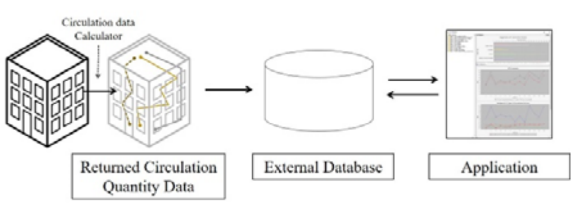

Figure 4. Establishing an external database and its application for circulation evaluation

6 Demonstration

6.1 Scenario of Circulation Evaluation

In this paper, a conceptual office building model which can be modelled in the early phase of design is used to demonstrate design evaluation. The target path objects includes 13 types of paths from different office rooms to a conference room which derived from a given BIM model as represented in Figure 5.

For planning office space, circulation is desirable to be designed in terms of efficient and reasonable spatial allocation and moreover induce workers to communicate formally or informally. In general, informal conversations in work place occur, usually involving people who are physically in close proximity to each other [20]. In terms of circulation, supporting informal communication between workers, this case study focuses two circulation data, the number of directly-accessible spaces of intermediate spaces and ratio of public space to overall passing spaces, as main factors for evaluation. According to its evaluation purpose, weights are assigned to each corresponding factor and data as described in Table 1.

Table 1. Assigning weights to each path objects

Circulation factor	$W(PF_i)$	Circulation data	$W(X_i)$
Relative Distance	0.2	Horizontal Distance	0.3
		Vertical Distance	0.7
Accessibility	0.3	Spatial depth	0.4
		The number of directly-accessible spaces	0.6
Simplicity	0.1	The number of turns	0.3
		Angle of turns	0.7
Pedestrian-friendly environment	0.4	Spatial volume	0.2
		Window area	0.3
		Ratio of public spaces	0.5

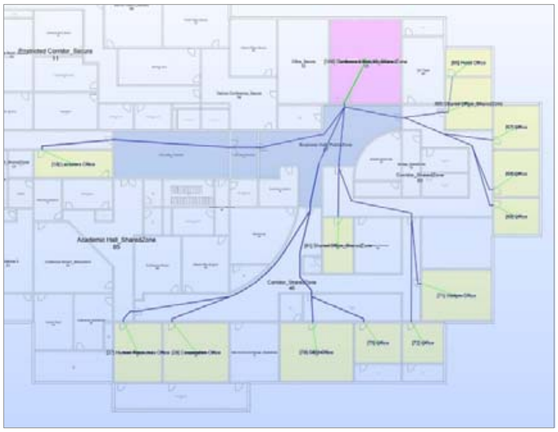

Figure 5. Target 13 path objects for evaluation based on the scenario; yellow (start spaces), red (end space), blue (public spaces)

6.2 Circulation Evaluation Result

Based on the scenario, we conducted circulation evaluation applying the framework through the implemented application. There are two ways of circulation evaluation approaches depending on weighting aspects.

1) Assigning same weight to all circulation factors (that implies circulation factors have the same importance)
2) Assigning different weight to circulation factors (that implies there is a different importance between circulation factors) (Table 1)

Figure 6 describes the result graph generated by the application. The gray-colored graph indicates series of PPV of 13 paths with the same weight and red-colored graph is relevant to PPV of the paths with different weight. WhenPPVs on two graphs are compared, paths with id=2, 10, 13 get highest PPV among alternatives. And most of path rankings stay same, however, 4 paths are changed in priorities. In case of path (id=7) with the distinguishing ranking difference, main reason for change comes from directly accessible spaces of the intermediate spaces and window area. The application reports not only for final evaluation results, but also intermediate result values of each path within the scope of each type of factor before deriving PPV. According to the reporting as shown in Figure 7, paths which are top 3 in PPV (id=2, 10, 13) are above average in almost all factor types.

The scenario-based evaluation approach can be applied diversely to different evaluation cases. For instance, evaluation results of this case study can be expanded to design evaluation case in terms of spatial allocation. By utilizing and comparing PPV and extra analysis information of design alternatives, designers can be supported to find a reasonable location for the conference starting from 13 offices.

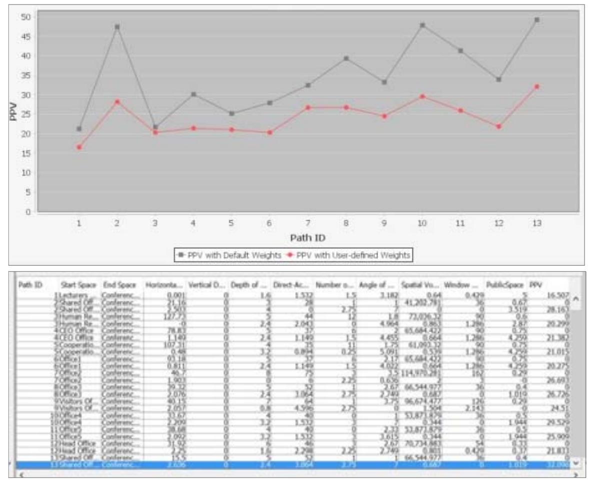

Figure 6. Scenario based circulation evaluation results of target 13 path objects - PPV Graph and Calculation table

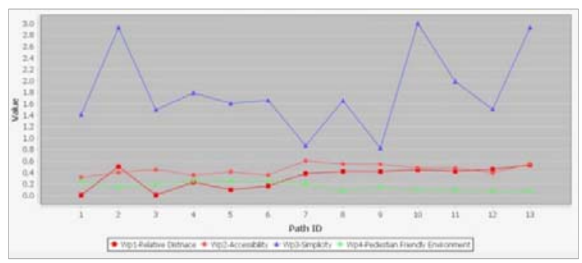

Figure 7. Scenario based circulation evaluation results of target 13 path objects - Intermediate result values graph

7 Conclusion

In terms of design analysis issues, this research aims to study BIM-enabled indoor circulation evaluation approach to dealing with qualitative circulation factors which have been excluded as a target of evaluation in BIM environment. In the early design phase, it is a main task to develop optimal design alternatives considering various design requirements according to building types or usages and building users. Thanks to building design supportive applications facilitated by BIM, explicit information derived from BIM models can play an important role of design analysis in the early design phase. The BIM-enabled design analysis approach has shown its capabilities that evaluate not only explicit factors, but also intrinsic circulation factors by using additional BIM-derived information, including metric distance, number of turns, depth and various quantitative data regarding circulation spaces as well.

This paper focuses on developing scenario-based circulation evaluation framework by applying BIM-enabled circulation data and parameters and demonstrating its applicability based on the idea of parameterizing circulation quantities. Circulation data is mapped with indoor circulation factors for evaluation and parameterized circulation data become adaptable factors depending on evaluation scenarios. The evaluation framework is composed of three parts, 1) path generation 2) parameterization of circulation data and 3) derivation of PPV of each path. The framework is demonstrated using a test model with specific scenario and circulation evaluation-purposed application that enables users to manage the framework easily. The evaluation results can play a role of objective indicators for users to get feedback promptly and effectively in the design development phase.

The suggested framework can be extended as defining additional circulation factors with BIM-enabled parameters. Furthermore, the scenario-based evaluation approach represented in this paper is expected to apply to other design analysis issues such as space program and energy analysis as one of the BIM-enabled evaluation methods.

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