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A Comparative Analysis of Performance Assessment Tools for Establishing Evaluation Framework for Sustainable Buildings

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Abstract Recently, the development of sustainable building assessment tools as means to invigorate the dissemination of sustainable buildings has been actively progressed. However, many assessment tools involve various problems in terms of assessment method and system framework, which greatly impede their credibility and applicability. If these problems persist over time, the role of sustainable building assessment tools as decision making measures during the design stage will be greatly limited. The objective of the study is to suggest a systematic model for sus- tainable building assessment tools by establishing a logical system of performance assessment framework. For this purpose, the Environmen- tal Impact Assessment(EIA) framework used in selected and modified to fit the building performance assessment. The analysis of performance assessment tools for sustainable buildings was conducted using the EIA framework. Based on the results of the analysis, a framework for the performance assessment of sustainable buildings was established.

Keywords: Sustainable Building, Assessment Tool, Environmental Impact, LCA, Weighting Factor

1. INTRODUCTION

Recently, as environmental problems such as resource depletion, nature destruction, and weather anomalies have become serious, the necessity of "sustainable development" has increased further. Buildings have very large environmental impacts because they consume various kinds of resources and discharge wastes. According to a report by the UNEP on sustainable buildings and construction, on average one-third of all energy is consumed by heat- ing/cooling and lighting in buildings (UNEP, 2003). The same report found that greenhouse gases discharged from buildings account for 40% of all greenhouse gases.

Many government agencies and research institutes have proposed various practical measures to reduce environmental impacts of buildings. One core measure involves the development of performance assessment tools. Such tools can help effective decision making because they enable understanding of the environmental impacts and eco- nomic benefits of buildings prior to their construction dur- ing design stage. They can also be used to encourage the construction of sustainable buildings.

However, the ability of existing performance assessment tools to achieve these objectives is limited (Glassen et al, 1994). In particular, unclear targets for the performance aspect sometimes make it hard to present the direction for sustainable buildings to pursue. Many tools also lack objectivity and accuracy. This reduces the reliability of the results of performance assessments and prevents the realization of sustainable building performance.

In Korea, there is increased recognition of the need for sustainable buildings and the development of performance assessment tools for realizing sustainable buildings has begun. If existing performance assessment tools are benchmarked without systematically analyzing them, the limitation of existing performance assessment tools may remain as they are. Therefore, to develop performance assessment tools, the limitations of existing performance assessment tools should be systematically analyzed, and a framework of performance assessment should be established based on the analysis.

2. RESEARCH SCOPE AND METHODOLOGY

In this study, to establish a performance assessment framework for sustainable buildings, existing performance assessment tools were examined and analyzed. For the analysis, the Environmental Impact Assessment(EIA) framework was employed and modified to fit the building performance assessment tools. This analytical frame con- sists of performance dimensions, methods and scopes of assessment, weighting factor, and presentation of results to ensure a systematic

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approach to the assessment methods. Based on the results of the analysis, a framework for the performance assessment of sustainable buildings was established.

3. ENVIRONMENTAL IMPACT ASSESSMENT (EIA)

3.1 Overview of EIA

The EIA was first developed as a legal system (National Environmental Policy Act, USA) for preventing environmental disasters in advance when the necessity of sound environment management and environmental sustainability had come to the fore. After this law was enacted, EIA became widespread during the last 30 years. Representative EIA methods include life cycle assessment, Damage Assessment, and Risk Assessment (Kellenberger, 2005). The EIA is intended to identify and predict the effects of legislation, policies, program development, projects, and operating procedures on the environment and on people's health and welfare, as well as analyzing information on the foregoing effects. Therefore, EIAs provide comprehensive information not only on environmental effects of proposed developments but also on economic and social ones.

3.2 EIA Framework

The EIA frameworks include systematic structure to analyze environmental impact assessment tools. These systematic frames consist of performance dimensions, methods and scopes of assessment, weighting factor, and presentation of results (Reijinders et al, 1999). In this structure, performance dimensions refer to the categories of performance which include environmental, economic and social categories. Some tools focus on environmental effects such as quantities of natural resources used, wastes produced. Other tools may also include social and economic effects. For example, LCA is used to investigate environmental effects while performance scores assessment may be used to look into all three dimensions. However, there is ambiguity of boundaries in each dimension like this: "Is depletion of the stock of resources an economic or an environmental issue?" (Josson, 2000)

The assessment of method can be divided into emphasis on procedure and emphasis on modelling. Emphasis on procedure determines whether the performance target has been met by assessing implemented processes. In contrast, modeling approaches focus on results rather than processes, modeling the final results to obtain an accurate assessment of the performance. Emphasis on modeling usually is de- veloped in the form of a computational algorithm; for example, a flow model with certain characteristics or a rigor- ous economic model.

The scope of assessment(spatial and temporal aspects) usually imply defining boundaries in space and time. Spatial modeling can be carried out in a number of ways. Some tools investigate only materials, some aggregate information from whole buildings and their sites. Temporal modeling can be divided into product, construction, operation, and waste stages.

The data used in different tools can be categorized according to whether they are concerned with quantitative and qualitative data. Appearance of output data are subject to how to present the results. The tools can deliver their output data in a more or less aggregated format. For example, results can be presented as single parameter, a few parameters or as many parameters.

Table 1. Structure of Environment Impact Assessment

Aspects	Categories
Performance Dimension	Main Dimension Environmental Economic Social
Method of Assessment	Emphasis on procedure Emphasis on Modeling
Scope of Assessment	Spatial Modeling One geographical area Many Geographical area No defined geographical areas Temporal modeling Snapshot view of a point in time(past, present, future) Snapshot view at intervals over a pe- riod of time Whole lifetime included
Presentation of results	Presentation of results Single parameters Few parameters Many parameters

4. PERFORMANCE ASSESSMENT TOOLS FOR SUS-TAINABLE BUILDINGS

4.1 Overview

Initial sustainable building performance assessments borrowed concepts and methods from EIAs. Since then, the concept and assessment methods of environmental performance have been continuously benchmarked. Recently, as interest in building sustainability has increased, the number of sustainable building performance assessment tools have also been grown rapidly. However, many of these performance assessment tools have repeatedly encountered the similar limitations, and remedial measures are required to address these issues. The EIA also experi- enced similar problems in the process of its development. To solve the problems, the EIA was developed on the systematic assessment frameworks. A similar approach should be taken for assessing sustainable buildings.

Sustainable building performance assessment methods that have been developed thus far can be largely divided into two categories: 1) performance score assessments based on scores and assessment criteria and 2) a precise quantitative assessment, including physical life cycles, based on quantitative input/output data obtained from material and energy flows (Flowler et al, 2006).

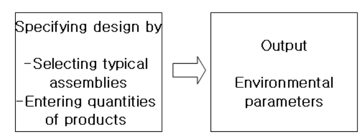
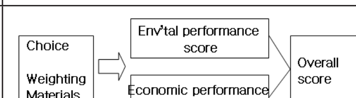
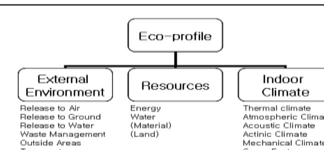
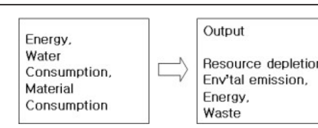
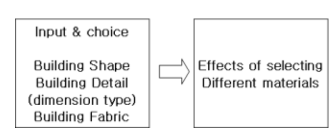
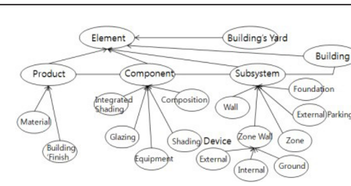
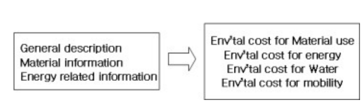
4.2 Performance score assessment tool (Rating System)

Performance score assessment tool has been rapidly dis- seminated over the last 10 years as part of diverse policies and regulations aimed at encouraging sustainable building construction. Well-known performance score assessment tools include SBTool, BREEAM, and LEED. Performance-based assessment is usually used to provide sus- tainable building performance certification. The method assesses the performance of a building with respect to individual criteria (Prescriptive Path). In most cases, the scores for the individual criteria are added up to obtain the overall score for the building.(Table 2)

Table 2. Performance Score Assessment Tools for Analysis

Tool	LEED (USGBC, USA)	BREEAM (BRE, UK)	CASBEE (JSBC,Japan)	SBTool (iiSBE, CA)
Market -Orientated	Fully market-oriented and strong market penetration	Market-orientation and strong market penetration	Moderate market oriented and high government involvement	Moderate market oriented
Flexibility	Increasing flexibility in USA and relative moderate flexibility in the overseas	Increasing flexibility in USA and relative moderate flexibility in the overseas	Increasing in flexibility in Japan and relative low flexibility in the overseas	High flexibility around the world
Assessment Category	Sustainable Site, Water Efficiency, Energy & Atmosphere, Material & Resource, Indoor Environmental Quali- ty, Innovation & Design Process	Management, Energy, Transport, Pollution, Materials, Water, Land Use and Ecology, Health and Wellbeing	Environmental Quality : Indoor Environment Quality of Service, Outdoor Envi- ronment on Site Environmental Load : Energy, Resources & Materials, Off-site Environment	Site Selection, Project Planning and Development, Energy and Resource Consumption, Environmental Loadings, Indoor Environmental Quality, Service Quality, Social and Economic aspects, Cultural and Perceptual Aspects
Weighting System	Yes (Consensus)	Yes (Consensus)	Yes	Yes (Consensus + Local Priority)
Life Cycle Coverage	Design, Construction, Operation	Design Construction, Operation	Under development, Design, Operation	Design, Construction, Operation
Results of Assessment	Sum of Each point of criteria	Sum of Each point of criteria	BEE = (Building Environmental Quality and performance) / (Building Environmental loading)	Sum of Each point of criteria

Table 3. LCA Tools for Analysis

Tool	Database and Assessment Method	Boundary of Assessment	Result of Assessment	Output	Basic Frame of Assessment Tool
ATHENA (ASI,Canada)	Various Database LCI – LCA	Construction materials and products and Assemblies	Environment Impact	Environmental Several Parameters (ex GWP, ODP)	
BEES 3.0 (NIST, USA)	LCA / LCC(Life Cycle Cost assessment) Based on ASTM Standard	Construction materials and products	Environment Impact Economic Performance	One Score	
ECO-PROFILE (DBUR, Denmark)	LCA	Construction materials and products, Operation(Only Occupant's Comfort)	External / Internal (Occupant's Comfort) Environment Impact	Performance Indicator Scores	
ECO-QUANTUM (IVAM, Netherland)	Huge Database LCA	Construction materials and products	Environment Impact	Environmental Several Parameters	
ENVEST (BRE, UK)	LCC LCA	Construction materials and products Operation	Environment Impact Economic Performance	One Score (Eco-point) (It presents other scores of alternatives simultaneously)	
EQUER (France)	LCA COMFIE : thermal environment simulation (renewable energy system : solar heat, PV module etc)	Construction materials and products Operation (including water use) Occupants' comfort	Environment Impact	One Score (Eco-profile)	
GREENCAL (NISE, Netherland)	LCA	Construction materials and products	Environment Impact	One Score (Impact is transferred to Environmental Cost, cost/m^2, 2000 point(Reference building : 100 point))	

4.3 Life Cycle Assessment tool (LCA tool)

Life cycle assessment(LCA) views environments as systems of energy and material use and links environmental pollution and resource depletion caused by buildings with relevant inputs and outputs (Lowe et al, 2000). Most performance assessment tools are based on the principle of LCA. LCA is regarded as a methodology that enables objective and scientific analysis of potential environmental impacts throughout the life of each building. It is increasingly utilized in all industrial fields, including construction, in Korea and elsewhere. However, commercial LCA assessment tools have only entered the market in the last decade. They have lower distribution ratios compared to performance score assessment tools, and they are not used as measures for policy development regarding sustainable buildings. Furthermore, as the development of LCA tools for the area of construction is quite complicated and difficult, these are mostly developed with major financial support from state governments and local governments.

Nevertheless, various attempts have been made recently to develop LCA tools, mainly in the U.S. and in Europe. The LEED, a representative performance score assessment tool, has been discussing with Athena, an institution involved in developing EIAs of construction materials since 2004, to include LCA method in the tool (Seo et al, 2005). Table 3 shows the types and characteristics of LCA tools.

5. COMPARATIVE ANALYSIS OF SUSTAINABLE BUILDING PERFORMANCE ASSESSMENT TOOLS

5.1 Selected Tools

The sustainable building performance assessment tools selected for the analysis are shown in Table 4. These selected performance assessment tools are well-recognized and have been widely used in many countries. As LCA tools require precise analysis of huge amounts of data, most of assessment tools utilize computer programs.

Table 4. Rating and LCA Tools for Analysis

Performance score assessment tool (Rating System)	Life Cycle Assessment Tools
BREEAM CASBEE LEED SBTool	ATHENA BEES3.0 Eco-profile Eco-Quantum EQUER Envest GreenCal

5.2 Dimensions of Performance assessment

Based on the EIA structure, the dimensions of performance for sustainable building can be divided into environmental, economic, and social dimensions. Most assessment tools evaluate the environmental impacts of buildings with respect to energy, material, and water re- sources. Only the SBTool, BEES 3.0, and Envest deal with the economic performance of buildings. The SBTool uses a qualitative approach rather than mathematical methods in the assessment of the economic performance of the items. With respect to the social performance of buildings, the scope is very wide. However, in most cases, it is limited to occupants' comfort/health. Only a few assessment tools deal with building sites, amenities in the surrounding environments, communities, and convenience of residents. LCAs are not used to determine a building's social performance, which is very much a qualitative concept. The Eco-Profile alone deals with the quality of indoor environments while aiming at a precise assessment of indoor total volatile organic compounds(TVOC).(Table 5)

Table 5. Performance Dimension

Name	Performance Dimension		
	Environmental	Economic	Social
BREAM	▪	-	▪(*IEQ)
CASBEE	▪	-	▪
LEED	▪	-	▪(*IEQ)
SBTool	▪	▪	▪(*IEQ)
ATEHNA	▪	-	-
BEES 3.0	▪	▪	-
Eco- Profile	▪	-	▪(*IAQ)
Eco- Quantum	▪	-	-
ENVEST	▪	▪	-
EQUER	▪	-	-
Greencal	▪	▪	

*IEQ : Indoor Environmental Quality
*IAQ: Indoor Air Quality

5.3 Method of Assessment

Although the assessment methods in the EIA system are divided into process approaches and modeling approaches, in this study, they were modified to prescriptive path (emphasis on procedure) and performance path (emphasis on modeling) to fit specific nature. (IEA ECBCS, 2004)

Prescriptive path approach can be used to assess diverse areas because it list and evaluate individual assessment criteria necessary to achieve the required performance. In contrast, performance path approach is limited in its scope of assessment because it assesses the overall performance based on mathematical algorithms (or modeling). Although performance path requires relatively more expertise and time for the assessment, the result can be more reliable and objective.

In general, performance score assessment tools use prescriptive path based on individual assessment criteria, and LCA tools utilize performance path based on mathematical algorithms (or modeling). However, the use of both approaches in one assessment tool is on the rise. In particular, the LEED, which basically employs prescriptive path, is increasingly using performance path in criteria that require precision. In contrast, efforts have also been made to include prescriptive path in ENVEST, which is based on complicated algorithms and computer programs. The integration of the assessment methods is intended to overcome the shortcomings of each path and improve the accuracy of the assessment results. (Table 6)

Table 6. Methods of Assessments

Name	Methods of Assessments	
	Prescriptive Path (Emphasis on Procedure)	Performance Path (Emphasis on Modeling)
BREAM	▪	-
CASBEE	▪	-
LEED	▪	▪
SBTool	▪	▪
ATEHNA	-	▪
BEES 3.0	-	▪
Eco- Profile	▪	-
Eco- Quantum	-	▪
EQUER	-	▪
ENVEST	▪	▪
Greencal	▪	▪

Table 7 . Time Boundary

Name	Time Boundary (Life Cycle)			
	Production	Construction	Operation & Manage -ment	Disposal
BREAM	▪	▪	▪	▪
CASBEE	▪	▪	▪	▪
LEED	▪	▪	▪	▪
SBTool	▪	-	▪	▪
ATEHNA	▪	▪	-	-
BEES 3.0	▪	-	-	-
EcoProfile	▪	▪	▪	▪
EcoQuantum	-	▪	-	-
EQUER	-	-	▪	-
ENVEST	▪	▪	▪	▪
Greencal	-	▪	-	▪

Table 8. Spatial Boundary

Name	Spatial Boundary			
	Material	Assem- blies	Whole Building	Site
BREAM	▪	-	▪	▪
CASBEE	▪	-	▪	▪
LEED	▪	-	▪	▪
SBTool	▪	-	▪	▪
ATEHNA	▪	▪	▪	-
BEES 3.0	▪	▪	-	-
EcoProfile	-	-	▪	-
EcoQuantum	▪	▪	-	-
EQUER	-	-	▪	-
ENVEST	-	▪	-	-
Greencal	-	▪	▪	-

5.4 Scopes of Assessments

Scopes of Assessments are generally divided into spatial modeling(spatial boundary) and temporal modeling(time boundary). A spatial boundary can be classified depending on the scope which has an impact on the results while time boundary can be explained as a point of time when assessment begins. Depending on environmental impact, a certain period from which the flow of environmental changes could be understood can be assessed, or the whole life can be assessed depending on circumstances.

In assessment, time boundary refers to the target period for assessment. In the past, most conventional LCA tools focused on construction materials. These days, however, there has been a tendency to see a building itself as 'product.' As a result, there have been attempts to cover a whole life from construction to operation. In case of EQUER and ENVEST, therefore, a simple building energy interpretation engine has been used for building assess- ment in operation stage. (Table 7)

In terms of spatial boundary, it can cover from whole space including building site to construction materials. In case of performance rating assessment, quantitative estimation is not included. In fact, the entire boundaries from building site to materials are usually covered. In case of LCA tools, on the contrary, precision analysis targeted a certain stage. In case of building site, however, spatial boundary is too large for precision assessment. Hence, it has been rarely dealt with in LCA. However, as it evolved into building characteristics-reflected LCA, it has been common to include it in the operating stage because unlike general products, a building has a whole life cycle. In addition, the CO_2 and waste production of building during the operating stage accounts for 40-70% against a whole life. However, there are many LCA tools which do not assess operation stage even though a whole building is set for spatial boundary. In particular, it's been known that even though ATHENA (LCA tool) covers a whole building, it does not assess the energy used during operation stage. It is just a sum of data on each material. Therefore, it is necessary to clarify and inform the meaning of scopes of assessment on a whole building to users. (Table 8)

5.5 Presentation of Results

1) Data Aggregation

The results are the last output data provided to users. Depending on the type of the results, their usage may vary. The final output data can be expressed either through integration of the results of each performance assessment, or as exact environmental values. They can be expressed as an integrated single index, few parameters, or many indicators depending on the level of integration of output data. The simpler output results are, the more lessened decision-making process can be. The analysis indicates that LCA tools tend to output assessment results as they are. In this case, it can difficult to inform the meaning of the output results to non-experts. In case of rating tools, on the contrary, it is common to use a single index by integrating assessment results and set ratings. Therefore, they are more widely used due to easy applicability. The integrated results can be used to compare design alternatives. They are also advantageous in figuring out the level of building sustainability at a glance. (Table 9)

2) Weighting factors

Weighting factors are used in the process of integrating the

Table 9. Data Aggregation

Name	Index	Data Aggregation
BREAM	Single	Weighting factors are applied to assessment items in individual areas, and the results are added up.
CASBEE	Single	Weighting factors are expressed as indexes to calculate the building environment efficiency (BEE).
LEED	Single	Weighting factors are applied to assessment items in individual areas, and the results are added up.
SBTool	Single	Weighting factors are applied to assessment items in individual areas, and the results are added up.
ATEHNA	Single	Performance scores are relative values that can be obtained when the performance of the building designated as a standard building is assumed to be zero (0). The final result is obtained by adding up the performances to obtain a single score
BEES 3.0	Few	The sum of the environmental performance (LCA approach) and the economic performance (ASTM LCC approach)
EcoProfile	Each Variable	Expressed in 3 domains : 4-6 Sub domains – 87 variables
EcoQuantum	EcoQua -ntum Score	Twelve environmental impact factors are categorized in four environmental areas. , and the weighted values are applied to express the factors as two indexes.
EQUER	Each Variable	The environmental impacts are subdivided into six separate areas and assessed.
ENVEST	UK Ecopoint	The environment data are separated into 12 environmental impacts.
Greencal	Environmental Cost	Relative scores of between 100 points and 2,000 points are awarded, with more points awarded for better performance, and the results are converted into environmental costs.

assessment results into single or several indexes. The reliability of the integrated data varies according to whether the weighting factors used in the process are based on objective and reliable methods. LCA tools assign weighting factors for individual environmental impacts based on the results of the LCA analysis. Although the weighting factors based on LCA are quite reliable because they are derived from quantitative data, the limitation is that the factors can only be applied to specific environmental performance. Another problem is that the meaning of each weighting factor cannot be easily explained to general users of the assessment tool. On the other hand, in the case of assessments tools based on performance score, the objectivity and the transparency of the method used to assign the weighting factors are relatively poor. Weighting factors are generally determined based on expert questionnaires or social consensus. In some cases, the results of the LCA may be included to improve the objectivity.(Table 10)

Table 10. Weighting Factors Assignment Method

Name	Weighting Factors assignment method		
	Questionaire	LCA	Questionaire Survey on Experts
BREAM	-	-	-
CASBEE	▪	-	▪
LEED	▪	-	▪
SBTool	▪	-	▪
ATEHNA	-	▪	-
BEES 3.0	-	▪	-
EcoProfile	-	▪	-
EcoQuantum	-	▪	-
EQUER	▪	▪	-
ENVEST	-	▪	-
Greencal	-	▪	-

6. CONCLUSION

The comparative analysis of performance assessment tools for sustainable buildings applying the EIA framework can be summarized as follows:

1) Performance dimensions can be divided into three categories: environmental, economic, and social. Currently, only a few assessment tools include economic performance, but economic performance is increasingly being included in assessments. The latter reflects the trend toward general performance assessments, which deal with a variety of aspects of the performance of sustainable buildings. As the number of factors to be assessed increases, a problem has appeared that assessment items not much as- sociated with sustainable buildings' performance are im- prudently included.

2) The methods of assessment can be largely divided into prescriptive path and performance path. Performance score assessment tools generally use prescriptive path, and LCA tools employ performance path. However, there is a recent trend toward the utilization of both paths. The methods are adopted to establish assessment methods appropriate for the characteristics of performances. However, due to the selection of inappropriate assessment methods, the data obtained may not be reliable, although the objectivity of the data is improved.

3) The scope of the assessment can be divided into spatial boundary and time boundary. The time boundary can be set to diverse lengths, ranging from a particular time point during the construction of a building. The spatial boundary can cover diverse areas ranging from construction materials to building sites. However, the scope is limited to buildings rather than entire building sites in many cases.

4) The presentation of results vary according to the data aggregation methods used to integrate the data. Weighting factors setting is used during the integration of the results of the assessment. The data obtained can be expressed as a single index or a number of parameters, depending on the degree of integration of the results. The degree of integration affects the usability of the output data, with simpler output data more usable. Some LCA tools were identified as outputting assessment results as they were thereby causing a problem that the results could be interpreted only by experts.

Table 11. Structural Framework of Performance Assessment Tools

Module	Aspects	Categories
Input Module	Dimension of performance	Main Dimension Environmental Economic Social
Assessment Module	Methods of Assessment	Prescriptive Path Performance Path
	Scope of Assessment	Spatial Boundary Material Assemblies Whole building Site Time Boundary Production Construction Operation Disposal
Output Module	Presentation of Results	Data Aggregation A Single Index A Few Indexes Many Indexes Weighting Factors Questionaire LCA Questionaire (Survey on Experts)

As a result of the analysis, a structural framework of performance assessment tools for sustainable buildings is suggested.(Table 11) The dimensions of the performance, the methods of assessment, the scope of the assessments, and the presentation of the results are frames that must be included in the tools. These frames are subdivided based on the goals of the assessment, the methods used, and the scope of the assessment.

The analysis of existing performance assessment tools has identified a number of problems with the present tools. These included the selection of assessment methods not appropriate for the goals of the assessment, ambiguous assessment scope, and reduced usability of the results of the assessment. These problems can be overcome by developing performance assessment tools based the proposed systematic structure derived from the EIA framework.

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