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Building Information Modeling (BIM) Implementation Strategies for Sustainable Infrastructure in Africa: The Case of Ethiopia

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***Abstract*—This study presents the key BIM implementation strategies for public infrastructure projects in developing countries, with an emphasis in the Ethiopian construction sector to enhance sustainability in the built environment. An empirical research approach was conducted using a structured questionnaire survey, initially validated though both content analysis. The statistical analysis results reveal that the BIM implementation drivers in the infrastructure sector are: adequate IT infrastructure, availability of standards and guidelines, and government policy for sustainable development goals. Further, the factor analysis resulted in constructs: organization, project, process, applications & tools, market, and information management. This paper can be beneficial to policy makers involved in public projects to facilitate BIM adoption in the project life cycle and meet the sustainable development goals in the infrastructure market.**

***Keywords*— BIM Implementation, Sustainability, Infrastructure Projects, Developing Countries, Africa, Ethiopia**

I. INTRODUCTION

The efficient delivery of infrastructure projects require sufficient budget, effective and sustainable design, innovation and collaboration among stakeholders (1)–(3). One of the critical factors that ensure the information flow between project team, communication among professionals in the project life cycle, and the overall success of infrastructure projects is the extent to which innovation and innovative process used in various phases of construction project (4), (5).

Adopting BIM and innovative procurement methods such as integrated project delivery method (IPD) in construction projects has been thought as an effective approach in managing workflow and enhancing sustainability of the built environment (6). In this respect, recent studies highlighted that developed countries such as United Kingdom, Germany, United States, Australia, and Hong Kong have devised a comprehensive BIM implementation strategy for sustainable infrastructure delivery in the Architecture, Engineering, Construction (AEC) industry (7), (8). These countries have developed various BIM adoption policies, guidelines and strategies in the past decade, to encourage and facilitate BIM implementation across their respective markets in the past decade (9), (10).

In recent years, BIM adoption studies in developing countries, particularly in Africa is improving with several African countries are moving towards the idea of innovation in the infrastructure sector. (11). However, although BIM adoption is improving in the construction sector, most recent studies only focuses on exploring the level of BIM awareness of in construction markets (12), and investigating the application, challenges and barriers of BIM adoption in the construction industry (13). In this context, Ma et al., (2020) reveals cultural barriers, in-country construction policies, and attention given to public and private projects influence the successful BIM implementation in the infrastructure sector. Similarly, prior studies reported various challenges associated with BIM adoption in construction projects; including unreliable technological infrastructures, and unavailability of professional skills (14). However, there is still a dearth of studies and methodologies in developing countries that focuses on BIM adoption in relation to organization and project characteristics.

Hence, the purpose of the present study is to identify and explore the critical BIM adoption strategies for public construction projects. The study also aims to investigate the perception of each participant groups (client, consultant, contractor, and academia) on the potential BIM adoption strategies. In addition, the paper discuss cross – country comparative analysis between developing countries. Moreover, the study also addresses the limitation of existing BIM adoption strategies in developing countries by highlighting potential practical implications and recommendations on how the findings can help speed up the BIM adoption process in public construction projects.

The findings of this study are believed to provide significant research data for construction firms to give attention for successful BIM implementation and sustainability principles in organizations as well as project levels. This study will also contribute to policy makers and government regulators in African countries to enhance the current level of BIM implementation for sustainable infrastructure delivery in the construction markets.

A. Application of BIM for Sustainable Infrastructure Delivery in the Built Environment

Achieving sustainable infrastructure entails concerted considerations all the way from inception to demolition stages. In contrary to the fact that the issue of sustainability is in vogue, its implementation in infrastructure development, particularly in developing countries such as Ethiopia is still at its infancy. In the traditional design and delivery approach where sustainability issues are not adequately addressed, and the resulting infrastructure becomes fragmented, highly unsustainable and vulnerable (15).

Due to presence of huge input and complex process in sustainable infrastructure design and delivery, the need for innovative information-based interventions like BIM is inevitable. While implementation of BIM in the developed world is very encouraging, its application in the developing countries, especially in the area of infrastructure is very much limited. In this regard, the role higher educational institutes play in the implementation and diffusion of this innovative process into the construction industry is vital (13).

II. LITERATURE REVIEW

Systematic literature review was conducted to identify the potential BIM adoption strategies using two of the biggest databases: Scopus, and Google Scholar. Keywords such as, "BIM Adoption Strategies", "BIM Adoption in Developing Countries" and "Critical Success Factors of BIM adoption" were used in the search. Then, the authors filtered 44 papers published in year 2016 and later. From this, 13 publications were further for the questionnaire development and the remaining 31 for analysis throughout the paper.

B. BIM Implementation Strategies in Public Infrastructure Projects

Successful implementation of BIM in construction projects requires an unprecedented effort and approach by professionals, business partners; and government support across the industry (16), (17). Recent developments pinpoint the BIM adoption strategies within different contexts: from industry, organization and project levels (7), (18).

Hochscheid & Halin, (2019) studied the factors that influence the BIM adoption and diffusion process in the construction sector. Similarly, Zhou et al., (2019) explored the potential applicability of the advanced lessons and BIM experiences cultivated from different countries to the development of concise BIM adoption strategies in China. Whereas, in the context of organizations, Liao (2018) explored organizational working culture and experts' role as BIM adoption drivers through people management in organizational structures, and attributes. Similarly, the process of successful BIM adoption strategies in terms of capacitating construction firms was explored by Ahn et al., (2016). More so, Asma, Hadzaman & Takim, (2020) investigated the governing criteria of client firm in BIM based construction projects.

In recent years, studies are emphasizing on exploring strategies that focus on BIM adoption in construction projects (9), (19). For instance, a study by Ozorhon and Karahan, (2017) examined the critical factors of adopting BIM in construction projects located Turkey, using a questionnaire survey. Ma et al., (2020) studied the BIM adoption strategies and diffusion techniques the in the Chinese construction projects. Moreover, Aljobaly and Banawi, (2020) evaluated the capacity of Saudi Arabia construction firms in adopting BIM to construction projects, using three major BIM attributes. The authors argued that cultural contextualities significantly affect BIM adoption in construction projects. Thus, having a country-wise BIM adoption policy with an emphasis of global adoption strategy is an important element.

Considering the majority of studies mainly focus on BIM strategies from market level, and the fact that more recent advancements emphasize project conditions, the present study aims to analyze and enhance potential BIM strategies from project perspectives in developing countries. Moreover, prior studies in developing countries don't differentiate between public and private sector. In this respect, this study fills the gap in the literature by exploring critical BIM adoption strategies in the context of public construction projects. The critical strategies identified from the literature are outlined in Table 1.

III. METHODOLOGY

The purpose of this study is to investigate the critical BIM adoption strategies that focus on public construction projects in developing countries. The empirical data was collected from professionals working in the Ethiopian construction sector, and analyzed through criticality analysis.
Achieving

C. *Identification of BIM Adoption Strategies from Review of Literature*

The current study conducted a systematic review of relevant literature to gain a broad view of the strategies from different countries, and avoid biased and inaccurate empirical analysis. In this regard, a total of 18 critical BIM adoption strategies were summarized taking into account recent studies conducted from specific project perspectives (Table 1).

Table 1: Summary of BIM Adoption Strategies from Literature Review

Item	BIM Adoption Factors	References
BS1	Strategic & adequate IT infrastructure	(20), (4), (14), (8), (21), (2)
BS2	Availability of financial resources for BIM adoption	(4), (14), (7), (22)
BS3	Effective senior leadership	(23), (20), (24), (11), (2)
BS4	Availability of technical support for employees	(4), (8), (21), (11), (25)
BS5	Collaborative working environment in firms	(20), (14), (24), (8), (7)
BS6	Government policy	(20), (4), (24), (22), (25)
BS7	Availability of quality control and Specifications	(23), (14), (7), (11), (2)
BS8	Appropriate legal parameters	(26), (14), (25), (2), (22)
BS9	Sufficient standards and guidelines for BIM adoption	(20), (4), (8), (21), (7),
BS10	Extent of BIM awareness	(26), (4), (14), (24), (22)
BS11	Coordination among stakeholders	(20), (24), (8), (25), (2)
BS12	Highly competent consultancy service	(4), (14), (8), (11), (11)
BS13	Sufficient interoperability data & information	(23), (26), (20), (14), (25)
BS14	Regular communication between parties	(20), (4), (14), (25), (2)
BS15	Appropriate choice of delivery & contract types	(23), (4), (24), (22), (11)
BS16	Managing risks associated with BIM	(23), (4), (14), (24)
BS17	Clear roles & responsibility of BIM usage	(20), (4), (14), (24), (2)
BS18	Managing workflow throughout project life cycle.	(20), (8), (25), (2), (22)

A. *Data Collection*

A 5-point Likert scale ranging from 1 = not critical, 2 = not quite critical, 3 = fairly critical, 4 = very critical and 5 = extremely critical, was adopted in this study to get the perception of professionals consisted of; clients, consultants, contractors and academia, and are currently working in public construction projects across Ethiopia. Prior studies suggest that a 5 point Likert scale has been proven to be useful for a reliable data analysis in similar investigations around the world (4), (14). The draft questionnaire then sent to four experienced professionals (2 in academia and 2 in the industry) for content validation. The content validation helps to validate certain BIM adoption strategies taken from the literature against the cultural and other related factors and the overall language usage in the questionnaire.

B. Pilot Study

The current study adopted a two-stage data collection technique. The first stage of the data collection was based on a pilot study consisting of 12 experts working in various construction projects in and around the city of Bahir Dar. The pilot study was conducted as a pretest of the draft questionnaire for the purpose of checking overall language usage, assessing the average time needed to fill out the questions, and checking the compatibility of statistical tools against the questionnaire format for the main data collection (second stage) and analysis.

C. Data Analysis

The analysis of data in the current study comprised of different statistical methods; including Kolmogorov-Smirnov, Cronbach's alpha, mean score analysis, principal component analysis and Kaiser-Meyer-Olkin test. A statistical software package IBM® SPSS® Statistics 23 was used to analyze the data.

D. Demography of Respondents used in this Study

After the completion of the pilot test, the revised questionnaire was then sent out to 181 experts in the field of architecture, civil engineering and construction using face to face meetings and emails. A total of 110 questionnaires were filled and returned back; which implies a 61% overall response rate. From these, after discarding incomplete questionnaires, 96 valid responses were taken for further analysis. In order to enhance the validity and reliability of responses, experts who has a 5 year or more professional experience in public construction projects in the Ethiopian construction sector were considered for the study. Table 2 describes the demographic profile of participants.

Table 2
Demographic Profile of Participants

Profile	Frequency	Percentage
Experience (Years)		
6 - 10	52	54%
11 – 15	34	35.5%
> 15	10	10.5%
Organization (Firm)		
Client	13	13.5%
Consultant	41	43%
Contractor	27	28%
Academia	15	15.5%

IV. FINDINGS

This section summarizes the findings of data collected from professionals working in public construction projects.

A. Normality and Reliability Tests

Initially, Kolmogorov-Smirnov normality test was conducted to check whether the data is normally distributed or not. The result indicated that the variables violated the assumption of normally distributions with a confidence interval of 95%. Thus, the null hypothesis is rejected, and it is concluded that non parametric statistical tests will be employed for further analysis. Similarly, Cronbach's alpha (α) test is used to test the reliability (internal consistency) of data collected through a questionnaire survey. The coefficient of α ranges between 0 and 1. The rule is, if the α-value is greater than or equal to 0.7, the measurement is said to be acceptable (27). In this study, an overall Cronbach's alpha value of 0.715 was recorded. Hence, the α value is in acceptable range, and the result is reliable.

B. Mean Score Rank

Mean score method is adopted to rank the responses of professionals working the Ethiopian public construction sector. Mean score ranking (M) is computed based on the mean (average) values associated with each factor / attribute (7). In this study, the mean value ranges between M = 4.48 and M = 3.23. Based on the result: "Strategic & adequate IT infrastructure" (M = 4.48), "Sufficient standards and guidelines for BIM adoption" (M = 4.47), and "Government policy" (M = 4.42), perceived as the top critical strategies of BIM implementation in Public construction projects. In contrast, strategies such as: "Managing risks associated with BIM" (M = 3.29), "Sufficient interoperability model data and information" (M = 3.28), and "Managing workflow throughout project life cycle" (M = 3.23), has the lowest mean values and perceived as the least critical BIM adoption strategies.

Furthermore, as it is shown in Table 3, the result illustrates that there is a similarity and consensus in the perception of the top 5 rankings by all participant groups (client, consultant, contractor, and academia). This is also in line with prior studies (8), (20). Table 3 illustrates the mean score results of all participant groups.

Table 3: Mean Score Ranking for BIM Adoption Strategies

Item	BIM Adoption Strategies	All Participants		Client		Consultant		Contractor		Academia	
		Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
BS1	Strategic & adequate IT infrastructure	4.48	1	4.54	3	4.46	3	4.41	2	4.6	2
BS9	Sufficient standards and guidelines for BIM Adoption	4.47	2	4.61	2	4.59	1	4.30	4	4.47	3
BS6	Government policy	4.42	3	4.62	1	4.34	6	4.48	1	4.32	8
BS12	Highly competent consultancy service	4.40	4	4.38	8	4.58	2	4.09	8	4.4	5
BS10	Extent of BIM awareness	4.35	5	4.52	5	4.39	5	4.00	9	4.73	1
BS11	Coordination among stakeholders	4.33	6	4.46	6	4.24	7	4.33	3	4.46	4
BS5	Collaborative working environment in firms	4.31	7	4.38	7	4.41	4	4.11	6	4.33	7
BS15	Appropriate choice of delivery & contract types	4.25	8	4.36	9	4.15	8	4.26	5	4.39	6
BS8	Appropriate legal parameters	4.09	9	4.53	4	3.98	10	4.10	7	4.00	10
BS17	Clear roles & responsibility in BIM usage	3.77	10	3.46	14	4.02	9	3.33	14	4.13	9
BS3	Effective senior leadership	3.56	11	3.62	12	3.66	11	3.41	12	3.53	11
BS7	Availability of quality control and specifications	3.46	12	3.69	10	3.54	14	3.37	13	3.20	15
BS4	Availability of technical support for employees	3.36	13	3.23	15	3.56	13	3.52	10	2.67	18
BS14	Regular communication between parties	3.32	14	3.68	11	3.41	15	3.22	15	2.93	17
BS2	Availability of financial resources for BIM adoption	3.31	15	2.92	18	3.61	12	3.07	16	3.27	14
BS16	Managing risks associated with BIM	3.29	16	3.15	17	3.22	17	3.44	11	3.33	13
BS13	Sufficient interoperability model data & information	3.28	17	3.15	16	3.37	16	3.06	17	3.52	12
BS18	Managing workflow throughout project life cycle	3.23	18	3.62	13	3.21	18	3.05	18	3.19	16

C. Principal Component Analysis

Criticality analysis (CA) also known as principal component analysis is used to test the criticality of BIM adoption strategies and relationship of variable factor loadings. CA is a statistical procedure which is used to obtain a simplified structure for a large data set (6). It is employed when various data measurements are analyzed on a certain item / factor (8). The lower limit for a factor loading value is 0.5. Ma et al., (2020) emphasized the importance of criticality analysis and determination of correlation coefficients for studies related to BIM implementation and the area of construction management in general.

Two rounds of factor analysis using varimax rotation method was conducted for BIM adoption strategies in Ethiopia. In the first round, both BS10 and BS11 had a higher component factor loading value of 0.468 and 0.361 respectively. Thus, since both strategies were less than 0.5 (the lower threshold value), they were discarded for further analysis. In contract, after eliminating both strategies, the second round of PCA analysis result shows an acceptable value for all factor loadings (See Table 4). The Kaiser-Meyer-Olkin test result also reveals an acceptable value of 0.637; any value larger than 0.6 is considered as good (6). Similarly, the ρ value of Bartlett's test result is 0.000. The rule is that any ρ value less than 0.001 is considered to be acceptable (7). Thus, the test result is acceptable.

Table 4 points out the rotated component matrix using Varimax. The rule is that item component values greater than 0.5 are considered to be acceptable in BIM adoption related studies (4). The values labeled in bold are all greater than 0.5, which in turn are acceptable. Based on the analysis, six latent factor components were identified, namely; Organizational, Application & Tools, Market Related, Information Management, Project, and Process (Table 4).

Organizational related factor is the first component identified in the analysis. This component is related to organization's structure, resource standing and competency (14). In this regard, the organizational related factors comprised of three strategies; *Availability of financial resources for BIM adoption (0.912), Effective senior leadership (0.870), and Availability of technical support for employees (0.784).*

The second component on the Varimax rotated matrix is, Application & Tools. It is related to the extent of software and hardware usage during each project stage, and the corresponding communication media used among experts and as well as parties. The Application & Tools component includes; *Sufficient interoperability model data & information (0.690), Competence consultancy (0.685), Regular communication b/n parties (0.601), and Strategic & adequate IT infrastructure (0.589).* In addition, the third one is Market Related component. It includes BIM adoption strategies such as, *Appropriate legal parameters (0.824), Managing risks associated with BIM (0.668), and Government policy (0.546).* Market strategies focus on the role of government in devising BIM policies and encouraging BIM adoption across the construction industry.

Similarly, Information Management component involves the flow of information and work accountability in relation to BIM usage in construction projects (25). Information Management component involves strategies*; Managing workflow throughout project life cycle (0.722), and Clear roles & responsibility in BIM usage (0.692).* Moreover, Project component is the fifth component in the Varimax rotated component matrix table. It is comprised of two strategies*; Availability of quality control and Specifications (0.768), and Collaborative working environment in firms (0.622).* Project includes, institutional working structure and activities with respect to coordination and quality assurance.

Lastly, the six component is outlined as Process. This component details the process within the choice of contract types and guidelines and the compatibility of project delivery systems in BIM projects (20). Both *Standards and guidelines for BIM (0.796), and Appropriate choice of delivery systems and contract types (0.674)* were identified as a Process component.

Table 4: Rotated Component Matrix using Varimax

BIM Adoption Strategies	Components					
	Organizational	Application & Tools	Market Related	Information Management	Project	Process
Availability of financial resources for BIM adoption	**0.912**	0.135	0.074	0.102	-0.009	-0.051
Effective senior leadership	**0.87**	0.14	0.079	0.055	-0.115	0.005
Availability of technical support for employees	**0.784**	0.01	-0.062	-0.054	0.222	-0.032
Sufficient interoperability model data & information	-0.105	**0.69**	0.028	0.382	0.346	-0.046
Highly competent competence consultancy	0.055	**0.685**	0.099	-0.108	-0.133	-0.006
Regular communication b/n parties	0.075	**0.601**	0.124	0.085	0.269	0.25
Strategic & adequate IT infrastructure	0.224	**0.589**	-0.133	0.119	-0.112	-0.034
Appropriate legal parameters	-0.022	-0.002	**0.824**	-0.106	0.083	-0.079
Managing risks associated with BIM	0.012	0.276	**0.668**	0.18	-0.057	0.164
Government policy	0.066	-0.102	**0.546**	0.216	0.087	0.01

Managing workflow throughout project life cycle	-0.09	0.266	0.186	**0.722**	-0.109	0.053
Clear roles & responsibility in BIM usage	0.142	-0.024	0.072	**0.692**	0.185	0.033
Availability of quality control and Specifications	-0.073	0.113	0.327	0.121	**0.768**	-0.087
Collaborative working environment in firms	0.434	-0.142	-0.268	-0.018	**0.622**	0.173
Sufficient standards and guidelines for BIM adoption	-0.175	0.098	0.090	-0.161	0.031	**0.796**
Appropriate choice of delivery & contract types	0.125	-0.027	-0.062	0.346	-0.028	**0.674**

V. DISCUSSION AND PRACTICAL IMPLICATIONS

The first stage of the results section was to conduct a mean score analysis for the purpose of ranking the critical BIM adoption strategies derived from the systematic literature review. Based on the findings, strategic & adequate IT infrastructure is the first BIM implementation driver. The extent of development of IT and the availability of related infrastructures directly affects BIM adoption in developing countries (28). In Nigeria for instance, studies highlighted that insufficient infrastructure is the major hinderance of BIM adoption in projects (11). To overcome the problem, these developing nations should consider the involvement of private sector in the development of IT infrastructure, especially in the Sub – Sharan African region. Similarly, the experts outlined that the government's involvement and initiative in devising policies and sufficient standards is vital to encourage BIM adoption, To support the above argument, the Ethiopian Project Management Institute (ECPMI) designed BIM adoption roadmap in 2016, with the aim of enhancing professionals BIM awareness, and encourage universities include BIM courses in their curriculums (29).

In the second stage, the authors examined the principal component analysis of the factors associated with BIM strategies in public construction projects. Criticality analysis is particularly important to pinpoint and prioritize critical BIM adoption strategies by providing clustering mechanisms (14). In this study, the criticality analysis results highlighted six latent factor components: Organizational, Application & Tools, Market Related, Information Management, Project, and Process.

Organization is the first component which emphasizes the organizational aspect of BIM adoption in public construction projects (23). Organizations are the key elements a construction project. Capacitating firms and enhancing the competency of each professionals in organizations allows for a smooth BIM adoption in construction projects (30).

The second component of the PCA analysis focus on Application & tools. Availability of hardware, software packages and the overall IT infrastructure is an integral part of BIM adoption process in projects (7). Similarly, market related factors are mainly related to government's role with respect to devising BIM policies and its engagement in the successful implementation of BIM across the market. Literature outlines that legal issues are still one of the challenges of BIM adoption in the construction sector (14). In this respect, the regulatory body should play a vital role towards devising appropriate legal and contractual obligations when it comes to BIM implementation in public construction projects (11).

Having clear roles, and responsibilities is one of the fundamental principles of BIM adoption in projects and requires careful attention with respect to project information management (20), (31). Studies suggest that a smooth BIM data communication can enhance the accuracy and compatibility of flow of information within organizational structures, and as well as between project stakeholders (26). In addition, managing project workflow information also helps professionals and top management team to make timely projects decisions in every aspect of the project (4).

Project aspect is also one of the critical constructs of BIM adoption process. As it is indicated in Table 4, contractors perceived that creating a collaborative working environment among major parties in a certain project in essential for successful BIM adoption. The reason could be the successful adoption of BIM in construction projects directly affects the contractor (14). Moreover, It's been known that public infrastructure projects take up a huge budget in developing countries (25). Thus, availability of sufficient BIM adoption guidelines and careful choice of contract types during the procurement stage greatly affects the overall Process of BIM implementation in public construction projects.

VI. CONCLUSION

BIM is an essential innovation that can enhance the overall construction business environment in emerging markets. Though adopting BIM in projects has several associated risks and challenges, devising comprehensive strategies is an essential tool in the successful implementation of BIM in public construction projects.

The current study highlighted strategic & adequate IT infrastructure, availability of sufficient standards and guideline, and government policy, as the most significant BIM adoption strategies. Whereas, managing risks associated with BIM, interoperability model data, and workflow management, are perceived as the least critical strategies of BIM adoption. Similarly, the study explored the level of agreement between the rankings of expert groups participated in the survey. Evidently, the findings reveal that the majority of expert groups agreed on their response except contractor vs consultant pair of groups. More so, the criticality analysis also contributes critical theoretical evidences and empirical justifications of BIM adoption strategies of construction projects by identifying key components such as; organization, application & tools, market, information management, project, and process. These constructs alone are not sufficient enablers of BIM adoption, although they are considered to be baseline mechanisms for incorporation of BIM in public construction projects.

Prior studies have been focusing on exploring the perception of client, consultants and contractor while neglecting academia in BIM adoption studies. However, this study incorporated the perception of experts in academia in examining critical BIM adoption strategies to get a better scope of results. The findings of the study provide theoretical implications and empirical validations to encourage BIM adoption initiatives in public construction projects. Similarly, the results can also be used as a benchmarking BIM adoption strategy to guide key business decisions for top tier management team and CEOs in the Ethiopian public construction sector. In addition, considering there are a dearth of BIM adoption studies in the developing nations, the paper can contribute practical implications to the existing BIM adoption strategical approaches in the literature.

Further, the cross – country comparative analysis helps to contextualize the findings in diverse construction markets, and helps in the development of a comprehensive BIM adoption strategy across the Sub – Saharan African region. The current study doesn't consider project types (residential, commercial, industrial) in the analysis, though it is common to explore BIM strategies in terms of generalized project concept (4), (7). Future studies can be extended on organizational BIM adoption case studies using different project types, project life cycle and exploitation of the relationship between BIM adoption and sustainability in public construction projects for a better understanding of BIM usage.

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