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How to tell if a BIM project is successful: A goal-driven approach

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ABSTRACT

This study investigates the applicability of a success level assessment model for building information modeling (BIM) projects (SLAM BIM). SLAM BIM is a goal-driven method for the sustainable evaluation of a BIM project's success. It was developed on the premise that a project's success cannot be evaluated without first identifying its goals; thus, key performance indicators (KPIs) can vary according to project goal. SLAM BIM consists of five steps for defining BIM goals, uses, KPIs, unit measurements, and data collection forms and processes. To identify appropriate BIM KPIs, the collectability, measurability, and comparability of the candidate BIM KPIs were considered. Data related to schedule, design errors, change orders, response time, and ROI were collected and analyzed in the two projects by using the SLAM BIM process. The validity of SLAM BIM was tested by applying SLAM BIM from the beginning to the end of two construction projects.

1. Introduction

Building information modeling (BIM) implementation is spreading rapidly worldwide and becoming a conventional design and construction practice in many advanced countries [1]. With the increasing acceptance of BIM to improve traditional drawing-based practices, the industry interest has shifted from how to adopt BIM to how to successfully implement BIM in projects.

Previous studies for evaluating BIM projects can be categorized into two parts: (1) methodologies for evaluating the technological or organizational maturity of a BIM project team and (2) case studies evaluating the benefits of BIM projects. Examples of the first category are bimSCORE [2], the BIM Proficiency Matrix [3], BIM Interactive Capability Maturity Model (I-CMM) [4], BIM Maturity Measure (BIMmm) [5,6], BIM QuickScan [7], BIm^3 [8], and macro-BIM adoption assessment model [9]. These studies evaluated the maturity levels of BIM projects without carefully considering whether or not the projects were successful. Although a BIM project with a higher maturity level has a higher likelihood of being accomplished successfully, these methods do not evaluate BIM project success directly. In addition, since these methods are based on lengthy surveys and interviews with project participants after project completion, it is difficult to collect information that accurately reflects all the stages of a project.

The second category measured the BIM benefits of projects through case studies, which contain comparative analyses of BIM vs. non-BIM projects by Giel et al. [10] and Barlish et al. [11] and return-on-investment (ROI) analyses by Autodesk [12], Sacks et al. [13,14], Lee et al. [15], and others [16–18]; however, these studies did not provide appropriate metrics to measure the success or maturity levels of the BIM projects under review. For example, the number of requests for information (RFIs), which is commonly used to measure quantitative BIM effects, cannot be applied in certain cultures, such as South Korea, where it is atypical to formally track RFIs except in special cases.

This study investigates the applicability of a method for evaluating the success of BIM projects called the Success Level Assessment Model for BIM Projects (SLAM BIM). SLAM BIM provides tools to evaluate if a BIM project is successful and to sustainably measure the success of a BIM project. The sustainability of SLAM BIM in this paper means the continuous measurement of the success of multiple BIM projects using the same set of evaluation criteria as well as a collection of evaluation criteria with minimal additional work needed by project participants [19]. To measure the success of a project, the goals should be defined first because the goals are not fixed but vary according to the project characteristics [20,21]. Although existing business management techniques, such as management by objectives (MBO) [20] and the balanced scorecard (BSC) [21], are goal-driven approaches to project success measurement, they do not consider BIM as a factor when determining and measuring key performance indicators (KPIs). SLAM BIM, which is a goal-driven method, was applied to two projects in South Korea to verify its applicability and identify issues related to the measurement of the success of BIM projects.

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In the second section of this paper, we briefly review previous studies on the performance measurement of BIM projects. Then, in the third and fourth sections, we introduce the SLAM BIM process and describe how it can be used and exemplified by two case studies. In the fifth section, we explain the results of the two case studies. Finally, we discuss the lessons learned from this study and present directions for overcoming the noted problems.

2. Literature review

Previous studies evaluating BIM projects can be summarized into two categories: (1) models or methods that evaluate the technological and/or organizational maturity of BIM project teams and quantitatively measure the benefits of BIM projects, and (2) case studies that demonstrate how certain benefits from BIM projects can be measured.

Examples of the evaluation methods, which are referred as a BIM capability evaluation model, a BIM capability maturity model, a BIM maturity model, and a BIM performance evaluation model, include bimSCORE [2], BPM [3], and BIM I-CMM [4] in the U.S., BIM QuickScan [7] and BIM Successvoorspellers [22] in the Netherlands, BIMmm [5,6] in the UK, and the BIm^3 and macro-BIM adoption assessment model [9] in Australia. These methods help participants improve performance by evaluating the maturity and strength of BIM business practices [23,24]. The methods have different goals, evaluation methods, structures, strengths, and weaknesses [7,25–27].

bimSCORE [2] and the virtual design and construction (VDC) scorecard [28] were developed based on BSC to evaluate the success and maturity of a BIM project based on its planning, adoption, technology, and performance. VDC Scorecard comprises two models based on the number of measures and depth of measurements, which are VDC Scorecard Express (22 measures) and VDC Scorecard Full (56 measures). bimSCORE is a commercial version of VDC scorecards developed by Stanford University. bimSCORE provides a service to compare the evaluation results with the results of similar BIM projects, and it proposes improvements using data from the database.

BPM [3] reviews the eight categories for BIM maturity assessment after completing each BIM project as follows: the physical accuracy of a model, integrated project delivery methodology, calculation mentality, location awareness, content creation, construction data, as-built modeling, and facility management (FM) data richness. The maximum BIM maturity score is 32 points. Certification levels regarding BIM maturity are classified into five groups according to the BIM maturity score: working toward BIM (0–12 points), certified (13–18), silver (19–24), gold (25–28), and platinum (29–32).

To assess the maturity level of BIM, BIM I-CMM [29] was developed by the Faculty Information Council (FIC) at the National Institute of Building Science (NIBS) in the U.S. in 2007 [29]. This model, which is based on a concept of the Capability Maturity Model (CMM) in software engineering, analyzes data richness, lifecycle views, roles or disciplines, business processes, delivery methods, timeliness/response, change management, graphical information, spatial capability, information accuracy, and interoperability/IFC support. The certification levels of BIM capability maturity within an organization are classified into six groups: not certified (0–39.9 points), minimum BIM (40–49.9), certified (50–69.9), silver (70–79.9), gold (80–89.9), and platinum (90–100).

Arup [5,6], which is one of the largest construction engineering companies in the world, proposes BIMmm to evaluate structural, mechanical, electrical, and public health aspects of BIM. The four aspects are composed of 21 secondary disciplines, such as lighting, fire, and façade. It additionally provides instruction on how to use collected data to identify gaps in strategies in the current status of a BIM project and make future investment decisions within an organization, including research, training, and software. Furthermore, the results can be used to benchmark the BIM performance of a project against that of others.

BIM QuickScan [30] evaluates the BIM competence of an organization and the scope of BIM implementation in other organizations. BIM QuickScan contains four evaluation categories and 10 perspectives to assess BIM performance: organization and management, mentality and culture, information structure and flow, and tools and application. The ten perspectives are tools, strategy, organization, resources, partners, mentality, culture, education, information flow, and open standards. BIM QuickScan provides measured scores of an organization or a project as well as the highest score of other organizations or projects in terms of each category on the website.

BIm^3, proposed by Succar et al. [31], evaluates five perspectives of BIM projects, such as the BIM capability stage, BIM maturity level, BIM competencies, organizational scale, and granularity levels. It is a triaxial knowledge model comprising BIM fields, BIM stages, and BIM lenses. The user then evaluates the BIM maturity level of a project or an organization and compares it with the maturity level at the targeted capability stage. Each evaluation criterion is evaluated at five levels, 'A' through 'E,' according to subjective judgments of an evaluator working without objective evaluation criteria. These methods evaluate BIM maturity levels effectively; however, they do not address the success of BIM projects quantitatively. Based on BIm^3, Succar et al. [9] improved the methodology for macro-BIM adoption assessment and planning by introducing five new adoption models, matrices, and charts. The five models introduced are composed of (1) nine areas for targeted BIM diffusion assessment and planning, (2) eight macro-components and milestones for assessing and comparing the BIM maturity of countries, (3) three macro-dynamics that clarify how diffusion unfolds within a market, (4) three approaches and nine actions for assessing, comparing, and planning adoption policies across markets, and (5) nine groups of macro-diffusion responsibilities or roles.

Although a BIM project with higher maturity may yield more benefits, these methods do not directly address how successful or beneficial a BIM project is. In addition, they rely heavily on lengthy surveys and interviews with project participants after a project, which may greatly reduce their sustainability. In particular, bimSCORE and BIM QuickScan include more than 50 evaluation factors. To improve evaluation methods, data that can be collected naturally during work processes should be used for evaluation. Furthermore, the methods do not explain the relationship between the purposes of BIM implementation and the performance of a project, since they utilize consistent evaluation factors regardless of the characteristics or BIM goals of the project.

The performance of BIM projects was measured using a VDC Scorecard and BIM QuickScan, but was not measured by the other three models. However, measuring project performance is important because the purpose of adopting BIM is to improve project performance. Setting appropriate BIM goals through considering project characteristics is the first step toward developing BIM execution planning and important for carrying out BIM projects successfully [19,32,33]. Required BIM capability or expected BIM performance can vary depending on the established BIM goals [19,34]. However, most BIM evaluation models evaluate BIM implementation levels without considering BIM goals. Although a VDC scorecard only contains the objectives of BIM implementation as an evaluation factor, it does not provide different sets of criteria and methods that vary according to BIM goals.

Another stream of related studies is generally referred to as BIM ROI studies, most of which were conducted as case studies. Table 1 lists the major BIM ROI studies. Some studies have attempted to measure BIM

Table 1
Previous studies on BIM ROI analysis.

Study	Analyzed BIM ROI
Giel et al. [10,37]	16%–1654%
Gilligan and Kunz [36]	140%–39,900%
Holder Construction [38]	300%–500%
Lee et al. [15]	22%–97%
Azhar et al. [35]	229%–32,900%
PCL Construction [38]	500% ROI
Sen [39]	735% ROI

ROI by statistically analyzing multiple projects [35,36], comparing several sets of similar projects [10,37], or using a well-defined ROI equation [12,15]; however, most studies have been conducted as a single case study [38,39] focusing on the best practice case, rather than as an academic paper. Furthermore, the case studies report only the final ROI value and often do not report how the ROI was calculated. This is mainly due to the additional work required for project engineers to collect the data required for ROI analysis. Another reason is that BIM is most beneficial in reducing errors through early design review and coordination [38,40–46], but it is difficult to convert the prevented errors (events that did not occur) into a monetary value. For this reason, some surveys, such as SmartMarket Report series [38,40–46], more frequently use perceived ROI as an index than actual ROI.

Some studies have proposed a formalized method for measuring the benefits of BIM or various information technologies [13,47,48]. Barak and Sacks [13] measured the improved productivity in structural engineering practices by comparing productivity for projects that used a BIM model with those that used 2D drawings. Barlish and Sullivan [11] developed a methodology to analyze the benefits of BIM, including RFIs, change orders, and project durations, according to the investment metrics of design and construction costs. They applied their methodology to both a BIM project and a non-BIM project for purposes of comparison. Love et al. [48] proposed an evaluation framework that considered the tangible cost effects, as well as the intangible benefits and indirect costs.

The success of any project depends on its predefined goals because a successful project is defined as a project that achieves its goals [19], regardless of whether it is a BIM project or not. This definition is similar to those of BSC [21] and MBO [20]. Therefore, the first step in evaluating the success of a project is to identify the project goals, and then a set of KPIs should be identified depending on the predefined goals. Although the high-level guidelines provided by these techniques can be applied to most projects, details on the inclusion of BIM in assessments have not yet been specified. SLAM BIM is a goal-driven method to sustainably evaluate the success of a BIM project. It focuses on the premise that a project's success cannot be evaluated without first identifying its goals; thus, KPIs vary according to the project goals. The following section describes the SLAM BIM method in detail.

3. Success level assessment model for BIM projects (SLAM BIM)

SLAM BIM involves five steps: determining the BIM goals, determining the BIM uses, identifying the BIM KPIs, developing the unit measurement, and developing the collection forms (Fig. 1). The details for each step are as follows.

1) BIM goal – Since success refers to whether a goal has been accomplished or not, we can measure success when goals are clearly defined. Therefore, the first step in evaluating the success of a BIM project is to define the goals for the specific project. Many BIM guidelines have indicated that it is also important to share these goals among project participants [49].

2) BIM use – A BIM use, which is also called a BIM service and function, is a unique task or procedure in a project where BIM is utilized to support the project's planning, design, construction, and operational processes [49]. The second step is to determine appropriate BIM uses by considering the goals defined in the first step because BIM uses can help achieve the predefined goals. Depending on the project participants and project characteristics, some BIM uses are required for every project while others are only suggested or optional [49]. To achieve a goal, more than one BIM use can be employed.

$$\mathrm{goal}(x) \rightarrow \{y|\mathrm{bimUse}(y)\}$$

Pennsylvania State University [49] and New York City [50] identified 25 BIM uses, which we used as a basic pool to determine a set of BIM uses; however, the list of BIM uses may be extended by BIM execution planners according to the characteristics of BIM projects.

3) BIM KPI – KPIs measure how close a company is to its strategic objectives [51–53]. To identify the appropriate performance indicators (PIs) for assessing the success of a project, two steps are required. A set of PIs may vary according to the BIM goals and uses determined in the previous two steps. Therefore, an ideal set of PIs should be capable of determining whether or not the goals have been achieved and of measuring the effects derived when specific BIM uses are implemented. Since the BIM goals and uses in a BIM project should be considered simultaneously, the candidate PIs for the project are the common PIs that exist in both PI sets, as shown in Fig. 2.

$$\mathrm{goal}(x) \rightarrow \{r|\mathrm{pi}(r)\}$$
$$\mathrm{bimUse}(y) \rightarrow \{s|\mathrm{pi}(s)\}$$
$$\{t|\mathrm{candidate\_pi}(x)\} \equiv \{r|\mathrm{pi}(r)\} \cap \{s|\mathrm{pi}(s)\}.$$

Nevertheless, since a list of KPIs can be changed according to project's characteristics, the candidate PIs should subsequently be reviewed to ascertain whether SLAM BIM includes quantitative and sustainable KPIs to measure the BIM performance of the project. Therefore, SLAM BIM determines a set of final KPIs by taking into account the measurability, collectability, and comparability of each PI identified in the first filtering process via a series of surveys with project participants [19]. The final KPIs include the PIs that received high scores for these three properties:

a) Measurability: Each KPI should be measurable using quantitative evaluation criteria.
b) Collectability: While the project participants conduct their daily work, they should be able to collect data to measure each KPI with minimal additional data input. Low collectability of KPIs can become burdensome to project participants and unsustainable over the term of the evaluation period.

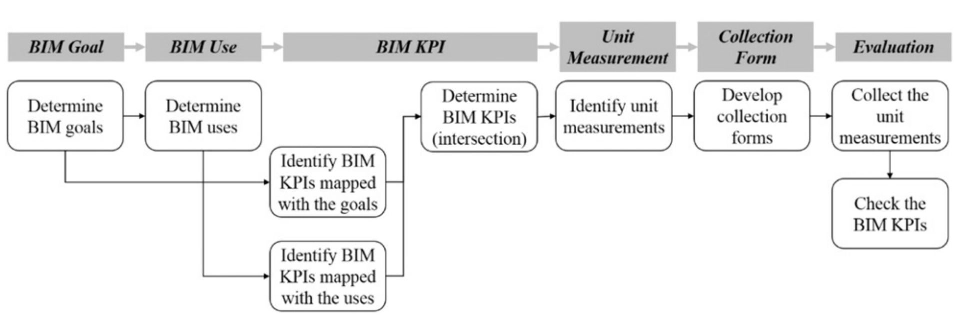

Fig. 1. The SLAM BIM process.

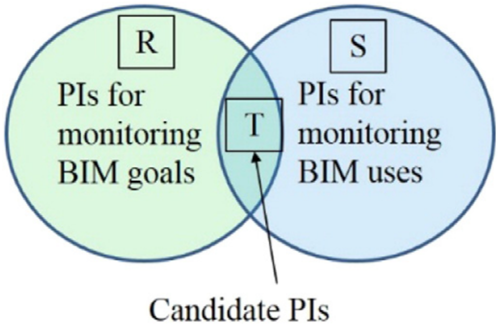

Fig. 2. Candidate PIs used to monitor the status of both BIM goals and uses.

c) Comparability: This refers to whether project participants can obtain a relative position of performance through comparison with a set of accumulated data of benchmarked cases or their non-BIM projects using a specific evaluation criterion.

4) Unit measurement – To measure the identified KPIs, it is necessary to specify the unit measurements. Some KPIs, like the number of change orders and the happiness level of the project participants, can be measured with a single unit measurement; however, most KPIs require more than one piece of information to measure them. For example, the date of the issue report and resolution may comprise a set of unit measurements for calculating the response time, and the actual and planned costs and schedules may be included in the unit measurement for cost overruns and schedule delays, respectively.

5) Collection form – Developing processes and forms for collecting unit measurements from construction sites is the final step in SLAM BIM. The data collection processes for each identified unit measurement should be non-invasive and integrated into existing work processes so as to reduce both additional workloads and the time project participants spend collecting data [19]. In addition, data collection forms should support the predefined data collection processes. For example, software applications can automate and support the report generation process. buildingSMART International has also formalized and standardized data collection processes and forms to support the coordination of component and space clashes and BIM collaboration between project participants. This is called the BIM collaboration format (BCF) [54]. Several BIM software programs, such as Solibri Model Checker, Tekla BIMsight, and DDS CAD, have implemented BCFs to support BIM collaboration processes. Consequently, the seamless integration of SLAM BIM with daily BIM work processes could facilitate the concept of BCF.

4. Case studies

4.1. Identification of BIM goals and uses

We applied SLAM BIM to two BIM projects in South Korea with different project characteristics and goals. BIM was implemented in the preconstruction and construction phases in both projects. The construction duration for the first and second projects was 10 and 11 months, respectively, and both projects were on a tight schedule.

The first case was a parking garage project whose main frame was made of precast concrete (Table 2). The BIM goals of this project were to improve communication, work efficiency, and technological capability, as well as to foster personnel with advanced BIM capabilities.

Table 2
General information and BIM goals and uses of the two cases.

	Case 1	Case 2
Project type	Parking garage	Sports complex (a baseball stadium and clubhouse)
Gross area	68,264 m^2	9995 m^2
Number of floors	4	4
Construction duration	10 months (July 2013–April 2014)	11 months (June 2013–April 2014)
Defined BIM goals	Improved communication Improved work efficiency Improved technological capability Advanced BIM capability BIM personnel training	Improved communication Improved constructability Reduced errors
Selected BIM uses	Design authoring Design review 3D design coordination Phase planning Quantity take-off Construction system design	Design authoring Design review 3D design coordination Phase planning Quantity take-off

Mechanical, electrical, and plumbing (MEP), architectural, and structural models had been developed by different project participants and were thus integrated to detect and coordinate clashes between the models. Design authoring, design review, 3D design coordination, phase planning, quantity take-off, and construction system design were identified as a set of appropriate BIM uses in the first project to achieve the defined BIM goals.

The second case is a sports complex project, including a baseball stadium and clubhouse (Table 2). The gross area of the second case was six times smaller than that of the first case. Three BIM goals were identified in the second project: improved communication, improved constructability, and a reduced number of errors. The common BIM goals in both the projects were to improve communication between project participants. Design authoring, design review, 3D design coordination, phase planning, and quantity take-off were employed as methods to achieve the three goals (Fig. 3). Although the different sets of BIM goals were defined in the first and second cases, the lists of BIM uses in both the projects were similar.

4.2. Identification of KPIs and unit measurements

Approximately 10 candidate PIs for both the projects were selected by considering the identified BIM goals and uses. A survey was subsequently conducted with the project participants to identify the final KPIs of the two projects by taking into account the measurability, collectability, and comparability of the candidate PIs. Six and five

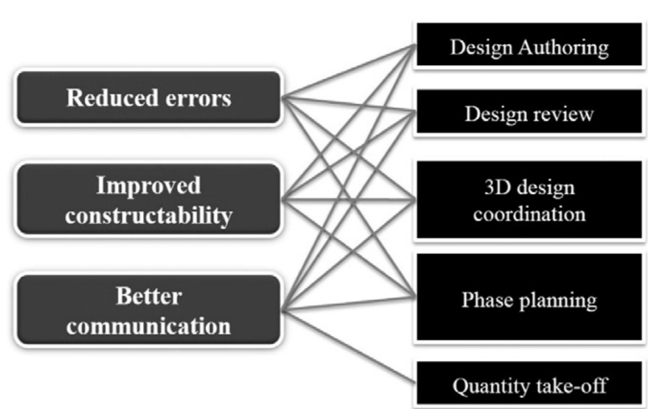

Fig. 3. An example of the relationships between BIM goals and uses (case 2).

respondents participated in the survey in the first and second projects, respectively. They comprised practitioners on the construction sites (five and two in the first and second projects, respectively) and at the headquarters (one and three in the first and second projects, respectively). Table 3 shows a list of the final candidate KPIs of the two projects and the agreement of core project team members on the collectability and measurability of each KPI in percentage terms. The number of candidate KPIs that were identified in both the projects was eight. Although most indicators could be comparable with data already collected, two indicators were not comparable with the data already collected since both projects were pilot BIM projects: actual cost–planned cost)/(additional cost for BIM implementation) and the number of risk factors detected using BIM. However, the indicators can be compared to data from other projects after data collection.

Fig. 4 shows lists of the unit measurements that were identified via interviews with the project participants in the two projects. Each KPI could be deconstructed into more than one unit measurement. Both of the projects identified 13 unit measurements to analyze the identified KPIs. The unit measurements collected from the first project with minimal additional input were similar to those of the second project despite differences between the project types and sizes, BIM goals and uses, participants, and so on.

4.3. Development of data collection forms and processes

In cases 1 and 2, nine and eight data collection forms to analyze the current work processes and measure the selected unit measurements were developed, respectively. Case 1 contained schedule reports, change orders, BIM issue and response reports, cost reports, site error or rework reports, safety reports, participant surveys, and the rate of initial inspections passed, while case 2 excluded the rate of initial inspections passed from the set of data collection forms. Existing forms, such as the BIM issue and response reports (Fig. 5), could be reused with minor revisions.

5. Application results

BIM performances of the two projects were measured using the identified candidate BIM KPIs (Table 4), the unit measurement, and data collection forms and processes. However, several candidate BIM KPIs were not utilized in the two projects due to difficulties of data collection. KPIs data that were planned but not collected in either project were rework- and defect-related data and were relevant to problems during or after construction. Candidate KPIs, which were not collected in case 1, included the number of change orders, the number of reworks, schedule conformance of major activities, and rate of passed initial inspections. For case 2, they were the number of reworks, rate passed initial inspections, cost and schedule conformance for major activities, percentage of activities completed without schedule delays, and total cost and schedule conformance. A comparison between the planned and actual costs and schedules was not meaningful in the second project, as the client significantly changed the original design and materials. Change order issues will be discussed in the next section. Consequently, the performance measured in the two projects was schedule conformance, design errors detected by BIM, change orders, response times of BIM issues, and partial BIM ROI. Most of the KPIs identified by SLAM BIM were collected and analyzed using the proposed data collection forms and processes. However, several KPIs related to problems during or after construction, e.g., reworks and inspect results, were not analyzed. Consequently, some BIM effects analyzed in the two projects were not compared with those of past or current projects using a traditional method due to unstructured BIM processes and/or a lack of required support.

5.1. Schedule

A schedule-related KPI was applied to the first project only. Case 1 was completed on time, according to the planned schedule of nine months, in spite of BIM implementation. However, unexpected problems were detected during construction in Case 1. Therefore, impacts on the schedule perceived by project participants of BIM implementation were explained in detail in the discussion section.

5.2. Design error

Design error data detected by BIM prior to construction was collected and analyzed for both projects. The various trends of design errors were analyzed according to causes, work types, and likelihood of identifying the errors without BIM. The causes of the errors were categorized into three types: illogical design, missing items, and discrepancies between drawings [15]. Illogical design involved clashes between building elements. Figs. 6 and 7 show the monthly trends of design errors detected by BIM prior to beginning construction for cases 1 and 2, respectively. Illogical design errors were the most common in both projects,

Table 3
List of candidate KPIs and agreement of project participants on collectability and measurability in cases 1 and 2.

Final candidate KPI	Case 1			Case 2		
		Agreement			Agreement	
	Result	Collectability	Measurability	Result	Collectability	Measurability
• (Actual cost–planned cost)/(additional cost for BIM implementation)	◯	100%	100%	◯	100%	80%
• Amount of change measured as change order cost over total contract cost	–	–	–	⦿	100%	100%
• Average response time to RFIs (or submittal approval)	⦿	100%	67%	⦿	80%	100%
• Cost conformance for major activities	–	–	–	⦿	80%	100%
• Number of change orders in project	⦿	83%	100%	⦿	100%	100%
• Number of errors and omissions in field	⦿	100%	100%	⦿	100%	80%
• Number of reworks	⦿	100%	100%	⦿	80%	100%
• Number of RFIs	⦿	100%	100%	–	–	–
• Number of risk factors detected using BIM	⦿	83%	100%	◯	80%	100%
• Percentage of activities completed without schedule delay	–	–	–	⦿	100%	100%
• Rate of passed initial inspections	⦿	67%	100%	–	–	–
• Schedule conformance of major activities	⦿	100%	83%	⦿	80%	100%
• Total cost conformance	–	–	–	⦿	80%	100%
• Total schedule conformance	⦿	100%	100%	⦿	100%	100%
• *Number of candidate final KPIs* (⦿)	9			10		
• *Number of candidate final KPIs* (◯)	1			2		
• *Total*	10			12		

⦿ denotes KPIs that are comparable with data already collected.
◯denotes KPIs that will be comparable after data collection.

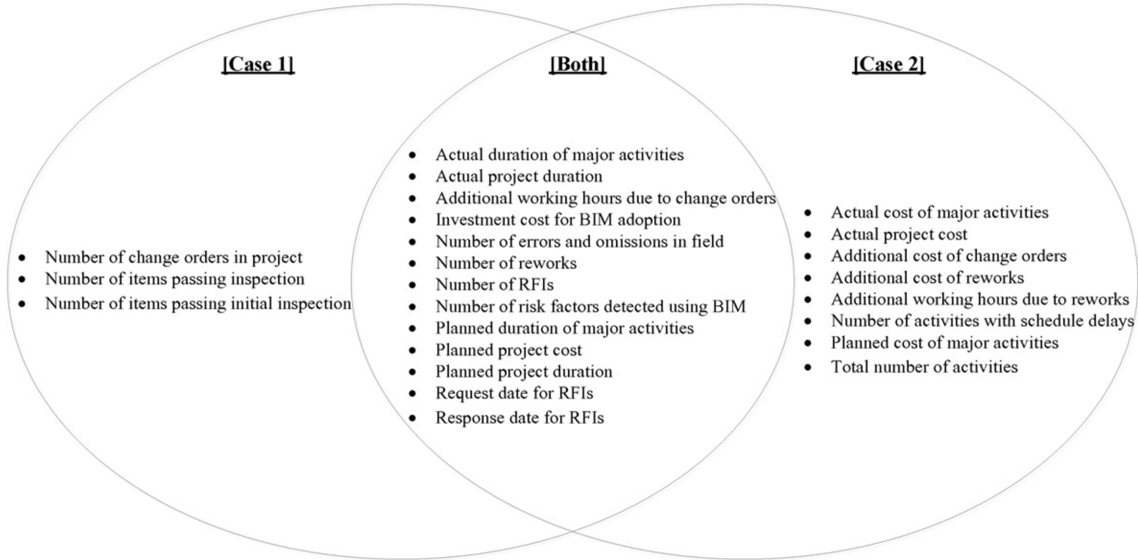

Fig. 4. Lists of the unit measurements required in cases 1 and 2.

compared to missing items and discrepancies. Based on these results, we analyzed trends in the design errors that were resolved and needed to be resolved, reporting our findings to the project participants in a regular BIM meeting (Fig. 8).

The work types in the two projects were architecture, structure, and MEP. The order of groups categorized by work type differed between the two cases, since the project characteristics were different. The likelihood of identifying each error without BIM was measured and utilized for calculation of impacts on project cost and ROI. The relationship between ROI and likelihood of identifying errors will be explained in a subsequent section.

5.3. Change order

KPIs related to change orders were collected in case 2 only. The analyzed KPIs were the number of change orders and amount of change

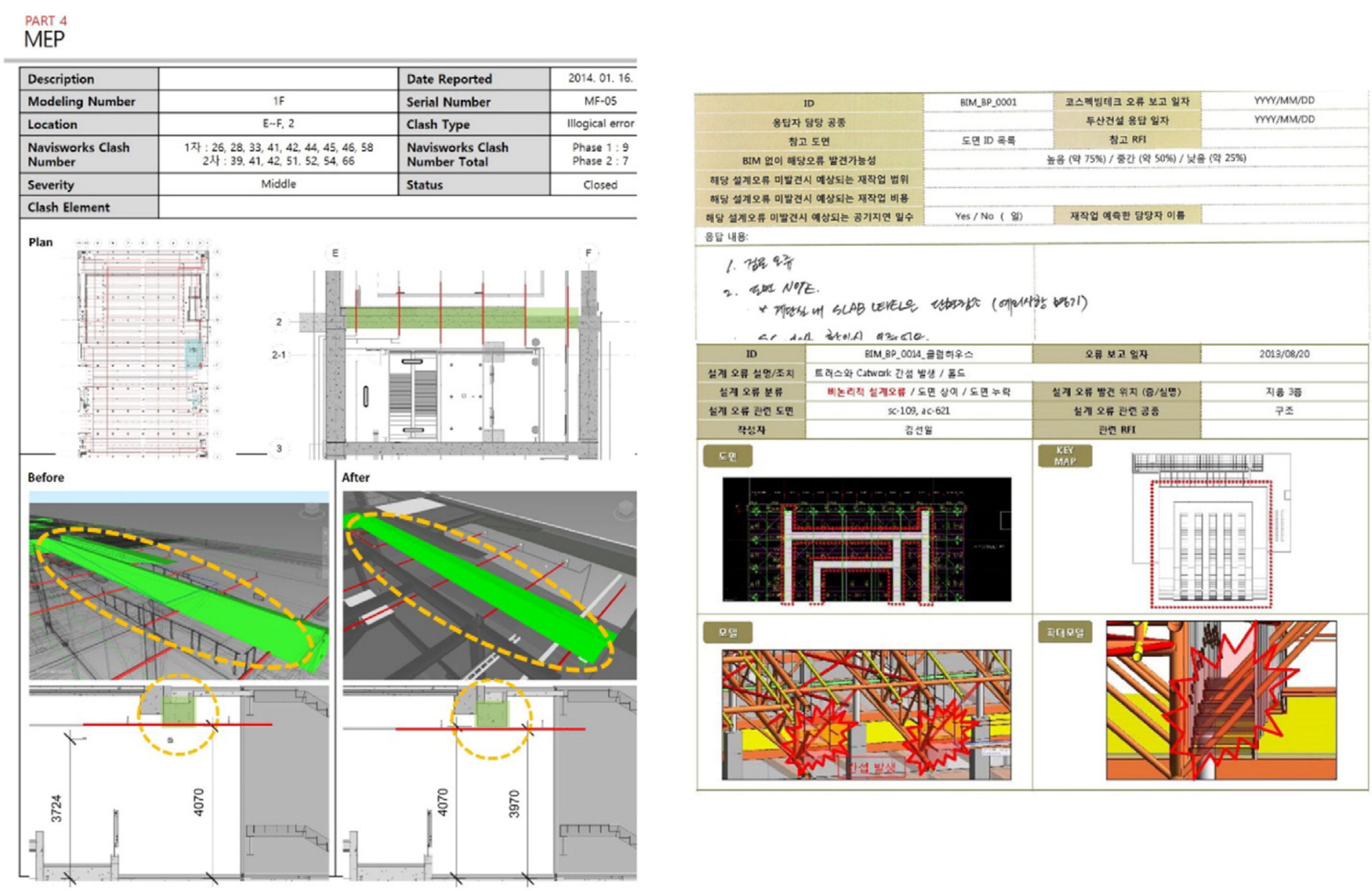

Fig. 5. Examples of the BIM issue and response reports applied to case study projects.

Table 4
Collected data in the two projects.

Collected data	Case 1	Case 2
• (Actual cost–planned cost)/(additional cost for BIM implementation)	○ (partially)	○ (partially)
• Amount of change measured as change order cost over total contract cost		○
• Average response time to RFIs (or submittal approval)	○	○
• Cost conformance for major activities		x
• Number of change orders in project	x	○
• Number of errors and omissions in field	○	○
• Number of reworks	x	x
• Number of RFIs	○	⊙
• Number of risk factors detected using BIM	○	
• Percentage of activities completed without schedule delay		x
• Rate of passed initial inspections	x	
• Schedule conformance of major activities	x	x
• Total cost conformance		x
• Total schedule conformance	○	x
• *Total number of used KPIs*	6	6

○denotes KPIs that were planned and collected.
X denotes KPIs that were planned but not collected.
⊙ denotes KPIs that were not planned but were collected.

measured as change order cost over total contract cost. In order to measure the BIM effects on change order issues, the data and results related to change orders in a BIM project should be compared to those in traditional projects whose size, type, and characteristics are similar to those of the BIM project. However, the contractor had not collected such data from previous projects; therefore, the comparisons were not conducted. Our collected data and results of the change orders are as follows.

Design changes in the second project were continued through the fifth month, with more than 80 change orders occurring during construction. About 70% of the change orders were client requests or drawing errors from a design firm differences between drawings and documents and the construction site. Change orders caused schedule delays and additional project costs.

The number of change orders and their impacts on project cost were measured according to work type (architecture, structure, and MEP) and causes. The number of change orders was not proportional to their impacts on project cost. The number of change orders caused by client request was the greatest; however, their impact on the overall project cost was minimal. Impacts from drawing errors were the greatest, with the amount of change measured as change order cost caused by drawing errors over total contract cost were more than three times greater than those caused by the client. Change orders associated with civil and architecture aspects increased the project cost, while change orders in the MEP area decreased the cost.

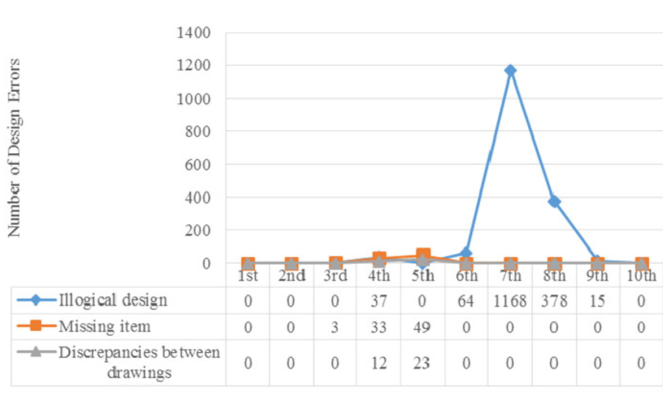

Fig. 6. Monthly trends of the number of design errors by cause (case 1).

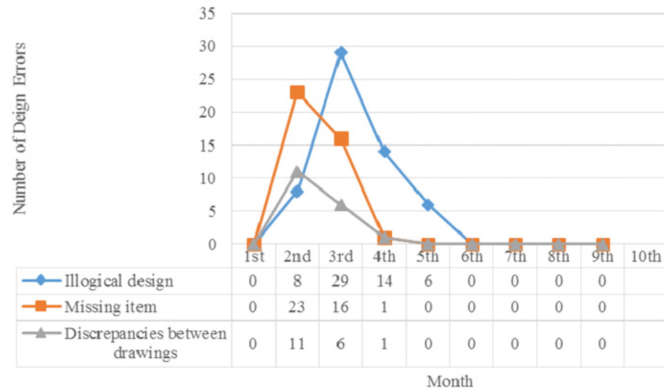

Fig. 7. Monthly trends of the number of design errors by cause (case 2).

5.4. Response time

Response within the required time is important to prevent schedule delays. There was a huge difference between the average response times for cases 1 and 2 (Fig. 9). In case 1, 83% of the issues was responded to within one week, while only 15% of the issues in case 2 garnered a response this quickly. Some issues in case 2 did not receive a response for longer than 15 weeks because there were too many change orders to keep up with. Unsurprisingly, the case 2 project was delayed by three months. Therefore, the two case studies show the potential for using response time as a KPI in order to predict project delay.

5.5. BIM ROI

We also measured the partial BIM ROI of the two cases, which concentrated on specific areas regarded as BIM effects. A quantitative BIM effect of case 1 was avoidance costs of reworks due to design errors. For case 2, it was the avoidance cost and reduced time by BIM-based quantity take-off. These factors were used as output data for calculating the BIM ROI of each project. The avoidance cost of reworks due to design errors referred to the costs saved by avoiding problems that could have been caused by design errors detected by BIM implementation before construction. Since some errors could be found without the BIM, the avoidance cost was calculated by multiplying the likelihood of not being able to identify design errors without the BIM and the indirect rate of the project. Sensitivity analyses of the BIM ROI of the two projects were conducted, in which we analyzed the changes in expected additional costs due to schedule delays. The range of the analyzed BIM ROI was −27% to 400%, although ROI analyses focused on partial

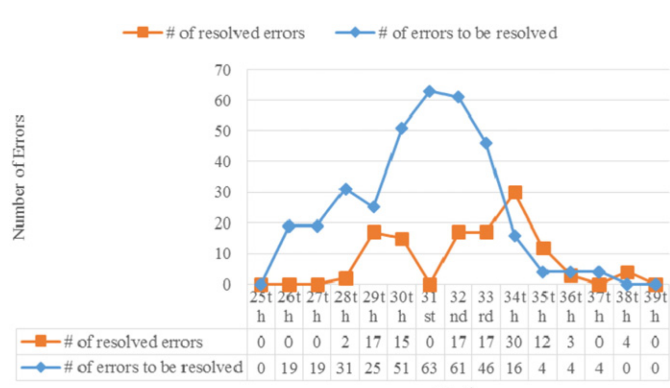

Fig. 8. Weekly trends of the number of design errors resolved and to be resolved (case 1).

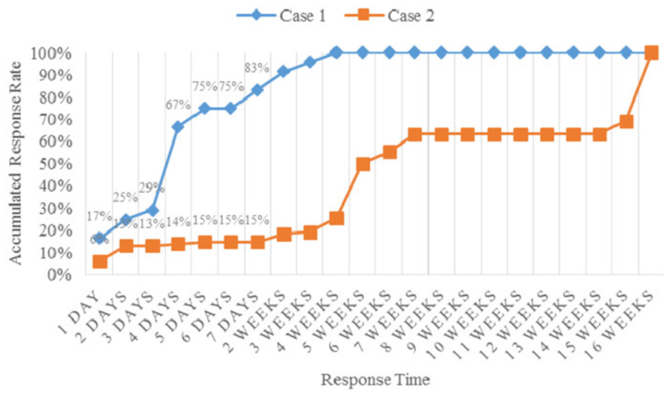

Fig. 9. Response time for issues in the two cases.

quantitative BIM effects. The equation to calculate the BIM ROI was based on that of Lee et al. [15]. Customized equations based on input and output data defined in Table 5 were applied to the two projects based on project characteristics.

6. Follow-up interviews and lessons learned

Follow-up interviews with practitioners who participated in the two projects and documented accounts were conducted to provide insights into individual perspectives and to gauge their experiences of the SLAM BIM application. Although qualitative data from interviews and document accounts did not contribute to quantitative analyses, it served as contextual information [11]. The individuals were asked if BIM caused positive or negative effects. The project participants agreed that SLAM BIM provided opportunities to continuously check and monitor the status of BIM implementation during the design and construction phases instead of evaluating after completion by applying the SLAM BIM process, including the data collection forms proposed in this paper. In addition, the qualitative effects of each category of KPIs were discussed to explore their positive applicability based on follow-up interviews and documented accounts.

Project participants were encouraged to share their experiences and comments during the interviews. From this, general obstacles that hinder practitioners and recommendation from receiving BIM benefits were highlighted in terms of the application of SLAM BIM in evaluating the success of a BIM project. The main lessons learned from the case studies are discussed in the following paragraphs.

The obstacles hindering the successful application of BIM, evidenced by this research, were inefficient design change processes and insufficient BIM training programs. Design should be coordinated early in a project cycle in order to stop endless design changes during construction and to efficiently manage BIM models and processes. Regardless of BIM implementation, endless design changes during construction increase the chances that a project will fail due to difficulties of managing project scheduling and risks. Rework caused by design changes have been regarded as obstacles for efficient decision making and project success [57–59] and have been reported to account for more than 10% of the total project costs [57]. BIM models that have been fully discussed, agreed upon, and coordinated before construction can significantly reduce the number of change orders and reworks caused by design errors [33]. In addition, a process to compare the as-built status to a BIM model should be defined for BIM management in the operation phase. Constructed areas might be different from the BIM models because of unexpected situations. In order to provide clients and users with an accurate model and to utilize the BIM models for the operation and maintenance phases, the differences between models and constructed areas should be reduced. An on-site BIM training program should be custom-designed for each practitioner according to role and should be a short-term training program focusing on the BIM software functions that can be immediately deployed by each practitioner. General BIM training programs that do not account for trainee roles and work scopes might prevent the trainees from learning and utilizing BIM. BIM functions that are complicated and relatively irrelevant to an individual's tasks may give trainees a negative perception of the process.

Second, historical data that can be compared to a new collection of BIM KPI data should be collected consistently. The values of many KPIs, such as response time, the number of reworks, and so on, are necessary for comparison with those in projects that have not implemented BIM in order to measure the quantitative effects. Although candidate KPIs in each project were determined by considering the comparability in the two projects, little of the data was comparable. This is not a BIM project-specific problem. Many construction companies in South Korea do not have a good database that contains accumulated projects or organizational performance data, except for those related to fundamental KPIs, such as cost overruns and schedule delays. Moreover, rework is usually performed by subcontractors (specialty contractors), whose performance data is more difficult to access and collect compared to that of a general contractor. Because of the lack of comparable data, an assessment of BIM projects that could be analyzed using a list of SLAM BIM KPIs was limited to the KPIs that did not need to be compared to those of previous projects using traditional methods. Accordingly, performance management, including the identification, measurement, and monitoring of appropriate indices should be conducted regardless of BIM implementation in order to collect meaningful comparable data. Furthermore, sustainable and continuous monitoring of the results measured by SLAM BIM will help improve the success of future BIM projects.

Table 5
Input and output data used in the BIM ROI analyses of the two projects.

Data type	Data	Required information	Case 1	Case 2
Input	Software cost	Additional software cost	○	○
	Hardware cost	Additional hardware cost	○	○
	BIM modeling and consulting fee	BIM modeling and consulting fee	○	○
	BIM training cost	BIM training cost		○
	Additional labor cost for BIM	Monthly labor cost for BIM	○	○
		Total number of BIM laborers		
		Total work months of BIM labor		
Output	Avoidance costs of rework due to design errors (direct and indirect cost)	Estimated direct cost potential of an error	○	○
		Likelihood of not being able to identify the error without BIM		
		Total number of design errors		
		Ratio of indirect costs to direct costs		
	Expected additional cost due to schedule delay	Weekly paid liquidated damages for delayed delivery	○	○
		Delayed number of weeks		
	Reduced time and cost for quantity take-off	Total expected time for quantity take-off using traditional methods		○
		Total time for quantity take-off using BIM		
		Monthly labor cost for quantify take-off		

Third, a mechanism to encourage the proactive participation of practitioners should be studied in order to align the construction management and BIM efforts. For this, we need a method for sharing project goals and the current status of BIM projects, which are analyzed through SLAM BIM KPIs, among project participants in real time. The concept of a project dashboard [60], a project monitoring system for providing intuitive information-delivery interfaces, is a good way of sharing such project information. Other ways to encourage project participants to utilize BIM and improve their performance associated with BIM are the introduction of management by objectives (MBO) and incentive programs. Shared goals and incentive programs are also commonly mentioned success factors for BIM implementation [61,62].

Lastly, a project management information system (PMIS) should be designed to support BIM processes and automate KPI data collection processes. A PMIS generally serves as one of the most important tools for clarifying and systemizing BIM execution plans, procedures, and monitoring [61,63]. Data collection can be a byproduct of using a proper PMIS. However, if a PMIS does not properly support construction and BIM practices, data collection becomes additional and redundant work. For example, in one of our cases, a new PMIS was developed to store and manage BIM data, including BIM models, minutes, RFIs, revision histories, and so forth. However, field engineers perceived the new PMIS as a redundant data report system to email-based data exchange and did not use the system regularly. This problem might be solved if an improved PMIS that functions like an email editor was available, although this approach cannot solve situations in which a project team persists in using oral- or paper-based work processes.

7. Conclusion

This study investigated the applicability of SLAM BIM, which is a goal-driven method for sustainably evaluating project success. SLAM BIM was established according to two main principles. The first principle is that the success of a BIM project can only be determined when the BIM implementation goals of the project are clearly defined, and a set of appropriate BIM KPIs can vary according to the BIM goals. The second principle is that KPI data collection should be sustainable. This means that the KPIs should be collectable through work processes with minimal additional effort. KPIs are defined based on the relationships between BIM goals, uses, and KPIs, and the development of processes and forms for collecting KPI data during work processes with minimal additional data collection processes is also included in SLAM BIM. SLAM BIM enables the project participants to intuitively check and manage the status of BIM implementation by increasing the possibility of continuous project performance monitoring during project implementation as well as comparing the evaluation results of various types of projects, including past, current, and future projects. SLAM BIM was applied to two BIM projects in South Korea. BIM goals and uses that were utilized in the two projects were considered to identify a list of candidate BIM KPIs. Collectability, measurability, and comparability of the candidate BIM KPIs were also investigated by the project participants of the two projects to extract the appropriate BIM KPIs for the projects. Consequently, BIM KPIs commonly utilized in the two projects were design errors detected by BIM, change orders, response times of BIM issues, and partial BIM ROI, while schedule-related KPIs were included in one project only. However, KPIs related to problems during or after construction, such as reworks and inspect results, were not analyzed in this paper. Effects of BIM implementation on design errors, change orders, and response time were not compared with those of past or current projects using a traditional method in additional to BIM technology due to the lack of comparable data and project participant motivation. The case studies also highlighted the importance of sharing SLAM BIM KPIs and data collection methods in the early stages of a project.

One of the limitations of this paper is the lack of comparable data collected from past projects using traditional methods as well as BIM because practitioners did not have the means to collect relevant data before accomplishing two pilot projects. With additional data collection using the proposed data collection forms and processes, we can analyze the quantitative impacts of SLAM BIM on BIM performance analysis in the future. Another limitation is that these forms did not integrate with a project management information system. The integrated system will be developed in the future to minimize the efforts for collecting and analyzing data and to monitor the status of BIM implementation in real time. Such an integrated system would encourage users to make an effort to improve performance without causing additional or redundant work. Furthermore, a project dashboard might be applied to monitor previous and current statuses and to share the ultimate goals and subsequent steps for improvement.

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