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Benefit–Cost Analysis of Building Information Modeling (BIM) in a Railway Site

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Abstract: Recent technological improvements have made substantial changes in construction industry. In specific, some technical applications, such as Building Information Modeling (BIM), open up many possibilities. Some studies have articulated the use of BIM and its advantages in construction, but most of them are theoretical, not practical. This study is to provide an insight to obstacles in BIM research. By investigating a real project that could utilize BIM in planning and construction phases, the authors try to investigate a possible outline of advantages in BIM implementation. The study area was set to a railway construction site in South Korea. The site covers multiple railway tracks, stations, telecommunication facilities, infrastructure facilities, railway structures, and so on. In the site, the authors have identified 12 errors in 7 projects that could be prevented if BIM was utilized before the construction. The total upfront costs required to provide a BIM for the seven projects was $116,348. On the other hand, the total costs required to fix the errors in the seven projects was $166,486. This can be regarded as the benefit of using BIM, because if BIM was implemented then the associated errors could easily be replaced. Therefore, the benefit–cost ratio can be estimated as 1.32 for one-month delay and 1.36 for a three-month delay.

Keywords: Building Information Modeling (BIM); Benefit-Cost Analysis (BCA); railway construction; liquidated damage; infrastructure; planning and design

1. Introduction

Recent technological improvements have made abundant changes in the construction industry. This is especially true in database management and data sciences. Specifically, some technical applications, such as Building Information Modeling (BIM), open up many possibilities for construction control and management. As many have noted, BIM provides nD Computer-Aided Drawing (CAD) services that are traditionally not available in many cases. It means BIM is an effective tool to manage construction process in a timely manner, and its information-oriented interface is a powerful tool for every step in construction. With its 3-dimensional ability along with versatility to control a vast amount of associated data, BIM is supported by many industry professionals.

However, despite the fact that many experts advocate BIM and support its utility, not many studies have identified the true effectiveness of BIM in reality. Some studies have articulated the use of BIM and its advantages in construction, but most of them are theoretical, not practical [1,2]. The majority of studies have adopted the utility of BIM in theoretical projects, giving a possibility for future use. Many of the studies emphasize the theoretical perspectives of using BIM and thus do not suggest a more specific argument in financial terms [3,4]. Therefore, its practical use and the impact of using BIM are still vague and unclearly identified. If BIM is an effective tool to support the construction industry and change the way we design a facility, then its advantages in terms of costs should be studied in a more detailed manner.

This study is to provide an insight to such obstacles in BIM research. By investigating a real project that could utilize BIM in planning and construction phases, the authors try to investigate possible advantages and disadvantages in BIM implementation. Conducting a benefit–cost analysis (BCA) would suggest a holistic view to similar BIM environment and articulating the sensitivity of BC ratio based on construction period difference may suggest more precise impact of BIM in construction industry.

2. Background

There have been a large amount of studies elaborating the benefits of using BIM in the construction industry. In less than 10 years, more than 900 studies regarding BIM utilization are published as academic papers, and most of them illustrate how BIM could change the construction industry and the world at large [4,5]. Among various studies, many have shown a great interest on how effective BIM is, and a large amount of efforts have been put to identify the benefits and obstacles in using BIM [3–6].

Some studies have identified that BIM technology can provide benefits in resource management and real-time cost control [7,8]. This can be regarded as a great advantage because the traditional non-BIM environment experiences difficulties in real-time solutions [3]. In addition, some studies have discovered that the benefits of BIM are in improvement of design quality, information sharing ability, reduction in construction and design errors, faster working environment, enhancing efficiency, operational efficiency, and so on [9]. With its abundant benefits, BIM utilization and its possible benefits can be divided into five categories: (1) lifecycle cost control; (2) effective construction process; (3) design and quality improvement; (4) decision-making support; and (5) risk management, and some are more abundant in specific cases, such as facilities management [10–12].

However, by closely observing the recent patterns in BIM studies, the vast majority of the existing literature relies on surveys, case studies, and interviews [11,13,14]. This is acceptable as a precise BCA may require higher standards and a large amount of data, and thus, sufficient information may not be feasible. Also, closely investigating the existing cases could enhance the validity of BIM benefits and still play an important role in expanding the use of BIM in the construction industry. Nonetheless, many have identified that a more precise cost–benefit analysis should be performed to capture the true benefits of using BIM [2,4,15]. In addition, more attention is now being paid that organizational and legal framework need significant adjustments to adopt BIM processes [2,4].

If we think about the benefits of BIM utilization, then some financial benefits and associated advantages should be elaborated to provide a more comprehensive perspective. There are studies describing benefits in risk management, construction time reduction, error management, and some other issues that may involve costs [6,12,16]. However, in many cases, precise measurements on financial costs of BIM utilization can hardly be accessible. As mentioned earlier, it may be due to data security as cost data generally involve greater scrutiny. Accessing cost data often requires private information, making it hard for a researcher to conduct a proper analysis. If what we want is to expand the utilization of BIM and its operating environment to make the construction industry more sustainable and smart, then precisely capturing the financial benefits of a BIM needs to be addressed.

3. Research Framework

3.1. Study Area and Data Analysis Procedure

This study was conducted in four steps. First, the authors made surveys and in-depth interviews with specific experts who worked in the study site to acquire how BIM would change their work environment in construction sites. By doing so, the authors discovered some projects that may have done a better job if BIM was utilized. During construction, some projects involved additional costs because of errors in drawings. By conducting interviews with relevant experts, the authors identified the errors that are relatively easy to be fixed with BIM. After that, each project was scrutinized with their existing datasets. Doing so allowed the authors to take a close look at what errors were made, and among which errors can be fixed with BIM utilization. Third, the authors estimated expected costs that may have increased due to the additional works to prevent the errors. Finally, a BCA was conducted with the existing cost data that are associated with the errors and the estimates that may have aroused to build a BIM.

The study area was set to a railway construction site in South Korea. Due to the regulatory requirements, a test bed was under construction to provide a more effective research environment for Korean railways studies. The site covers a multiple railway tracks, stations, telecommunication facilities, infrastructure facilities, railway structures, and so on. For that reason, BIM could be utilized to enhance the construction experience and receive financial benefits in construction and planning phases. The planning and design stage was conducted by a consortium of eight different engineering firms and the construction was carried out by a consortium of nine different semi-contractors. The total budget was approximately $25 million and the expected duration of completion was about 51 months. The construction is in its last stage and expected to be finalized in December 2018.

The authors selected this site because the test bed could become an important data generator providing more specific outcomes of BIM utilization. In addition, due to its complex bureaucratic environment, BIM was conducted during the planning and design stage, but not actively implemented in the construction process. It means despite the fact that a BIM was constructed for the entire facility, the construction process was carried out with traditional 2D drawings. There are many reasons for such contradiction, but the main reason mostly came from the uncoordinated administrative processes. If BIM is at hand to support construction stage but not adopted because of bureaucratic and legal reasons, then what is the purpose of implementing BIM in reality? This is one of the main questions for this research, and the authors tried to estimate possible benefits of actively using BIM.

To precisely capture the benefits of using BIM in a railway construction and to prevent any misinterpretation of BIM implementation, the authors conducted a series of meetings with the relevant professionals. Using a Delphi survey and an in-depth interview, experts were divided into three different stages, planning, design, and construction, and the Delphi survey was conducted for five different times. The Delphi method is a handy way to facilitate communication among participants. Relevant experts review questionnaires for more than two rounds, and all participants understand the importance of agendas, creating consensus and hierarchy in the decision making process [17]. In fact, if the use of BIM in a project should be fully captured, then the maintenance and operating stage have to be incorporated as these two are probably the biggest benefits that BIM could create. However, since the test bed site was still under the construction and thus, only planning, design, and construction phases were feasibly inclusive, the authors only considered the three aspects of BIM utilization.

All the relevant datasets were collected from stakeholders. As mentioned, the planning and design stage involved a BIM and thus, there were available data to estimate the associated costs, times, and other resources. The authors received all the relevant data from the responsible design firms to estimate costs and benefits. However, some issues incurred as the construction phase did not involve any BIM. Although there has been a general consensus about the advantages of using a BIM, some administrative process and legal requirements are not fully arranged to actively implement a BIM during construction. The same circumstances are observed in this study and the BIM that were constructed during planning stage could not be used in construction. Nonetheless, as this will become a longitudinal study, the authors think more data will be available once the site is done with construction and moves into its operation stage.

Based on meetings and interviews with relevant experts, the authors understood that capturing BIM's benefits in a project has limited capabilities. It means the advantages of using a BIM can be diagnosed by a small number of indicators. This is understandable, as construction involves a large number of people with diverse work steps and for that reason, the data availability could become a critical factor. In addition, construction process involves a number of unpredictable events, such as natural disaster and man-made mistakes. Hence, detailed documentation about planning, design, and construction is not always available in many cases. Therefore, including all details and elaborated measures in BIM BCA is not feasible in general. This study is not far from such circumstances, the authors have included selected measurements to estimate BIM benefits in a railway construction site. During the survey and interviews with the stakeholders, the authors asked what type of advantages could be achieved if the supplied BIM was utilized during construction. In addition, there have been in-depth interviews with engineers about the difficulties and advantages of using a BIM to handle the associated errors in traditional 2D CAD environment.

The study mainly focuses on three areas for the benefits of using a BIM: (1) design review; (2) reorder and reconstruct; and (3) delayed construction. Design review is to assess if there is any cost reductions or increase to fix design errors. BIM is an effective tool to capture any interference in design elements as it supports model checking capability. Hence, design errors could be eliminated when BIM is implemented at the beginning of construction stage. After that, reorder and reconstruct is measured to gauge any build orders are permitted with existing errors associated with it. If this happens, then construction process can be delayed and other relevant costs could incur because of the possibility of reworks. Finally, if errors are carried out throughout the planning, design, and construction stages, then the entire construction period could be delayed, which in return affects the liquidated damage. Although these three measurements are not holistic measurements to cover the total benefits of using BIM, estimating the three would provide an insight about the utility of BIM implementation in a real project.

After the initial BCA elements boundary was set, the authors collected data for corresponding workflows. In this case, there were seven construction projects that may have heavily required BIM. Table 1 depicts seven construction projects that were carried out with errors and for that reason, reworks and associated costs were increased. More errors can be found in the entire railway construction process, but based on interviews and surveys with the relevant experts, the below seven projects were identified as the closest projects that could be easily fixed with BIM. It means the below seven projects could be the potential works that can eliminate errors if BIM was implemented beforehand.

Table 1. Seven projects inducing errors.

Seven Projects with Building Information Modeling (BIM) Implementation						
The 1st Bridge	The 5th Bridge	The 7th Bridge	The 8th Bridge	Test Bed Bridge	The 6th Tunnel	Railway Tracks

As can be seen, most of them are bridge construction and only two projects involve tunnel and railway tracks. This is plausible as BIM generally requires 3D figures and bridges are the most common structural component in railway construction. Tunnels and railway tracks are possible components for BIM utilization but as the experts noted, it sometimes is a hard job as tunnel and tracks should be customized at a site scale, requiring different works in different circumstances. Therefore, it could be noted that most of BIM utilization is inclined to structural elements at this point.

3.2. Cost and Benefit Elements Standards

During the data mining process for the seven projects, the authors have identified 12 errors that could be prevented if BIM was utilized before the construction. These errors are identified based on rework orders that are made by engineers to fix the problems. In addition, during the interviews, the authors confirmed that the errors are relatively easy to fix with the BIM. Most of them are dimension errors or structural interference, and they are considered easy tasks for BIM modelers to deal with the model checker function. In this sense, the authors estimated possible costs that are required to fix the 12 issues and estimated possible benefits that can be assessed if those errors are fixed beforehand.

Table 2 illustrates all of the 12 events that happened during the construction process and possible benefits that could be provided if BIM was implemented at the beginning of construction phase. As can be seen, most of the errors are associated with structural interferences or mismatch of drawing details. This type of errors can be captured in traditional CAD environment as well. However, due to its 3D capability, a BIM can automatically calculate mismatch or interferences on its platform. It means identifying drawing errors in BIM environment is much easier and simpler when compared to the traditional 2D-based CAD environment. The traditional 2D CAD environment requires longer man-hours and more human resources to complete the same tasks.

Table 2. Twelve errors in seven projects without BIM utilization.

Project Names	Errors	Category	Benefits if Fixed
The 1st Bridge	Retail wall and bridge interference	Drawing change	Prevent rework
The 1st Bridge	Railway location mismatch	Dimension change	Prevent rework
The 1st Bridge	Girder and column level mismatch	Dimension change	Prevent rework
The 5th Bridge	Column elevation mismatch	Dimension change	Prevent rework
The 7th Bridge	Site elevation and drawing mismatch	Dimension change	Prevent rework
The 7th Bridge	Plan and side elevation mismatch	Dimension change	Prevent rework
The 7th Bridge	Section slope errors	Dimension change	Prevent rework
The 8th Bridge	Dimension errors	Dimension change	Prevent rework
The 8th Bridge	Girder and column mismatch	Dimension change	Prevent rework
The 6th Tunnel	Site boundary and entrance circulation interference	Interference simulation	Prevent rework and code violation
Test Bed Bridge	Structural interference	Redraw	Prevent rework
Railway Tracks	Girder elements miscalculation	Recalculate	Prevent rework

4. Analysis and Results

4.1. Cost Estimate

The first step in the cost estimation is calculating the costs that are expected to increase if BIM is applied to fix the above issues. To do so, the authors have divided the work force into two types and two processes. In general, BIM can be carried out by single person, whereas some cases demand multiple experts. Hence, BIM labor is divided into two types: single and multiple labors. After that, implementation process is also divided into two: (1) making BIM itself; and (2) site investigation for BIM implementation.

All seven projects were diagnosed if BIM was conducted before construction. Using the information from eight engineering firms who were contracted to do design and planning, man-hour and unit fees data are available. As shown in Table 3, each project was investigated to decide the proper type and process of labor it demands. First, the process of each project was diagnosed, and as can be seen, BIM implementation requires two processes: BIM work and site investigation for BIM implementation. BIM work requires BIM experts, whereas site investigation demands professional engineers and thus, the labor cost should be distinguished. According to the interview results, BIM experts are generally divided into three levels: BIM manager, BIM coordinator, and BIM modeler, where the manager is the highest paid and the modeler is the novice. In addition, professional engineers in Korea are divided into three levels: beginner, intermediate, and professional, where the beginner is paid as the lowest and the professional is the highest. Subsequent to process determination, work type was decided to provide if the work should be done with a single labor or a collaboration of multiple workers. In some cases, both modeling and site investigation could be done with multiple labors, whereas in some other cases, BIM works need just a single labor and site works need multiple labor forces. Table 3 depicts the detailed work forces, processes, and types.

Table 3. Types and process of labor and cost estimates.

Labor Cost Division	**Types**		Single Labor	(Daily labor fee) × (man-hour/8 h) × (No. of labor)				
			Multiple Labor	(Daily labor fee) × (man-hour/8 h) × (No. of labor)				
	Process		A-1	BIM work at office				
			A-2	Site investigation for BIM implementation				
Projects	**Process**	**Type**	**Level**	**Man-hour**	**No. of labor**	**Daily fee**	**Estimates**	
The 1st Bridge	A-1	Multi	BIM Manager	30	1	$873	$3274	$22,355
			BIM Coordinator	60	1	$729	$5468	
			BIM Modeler	120	1	$551	$8265	
	A-2		Professional	26	1	$977	$3175	
			Intermediate	26	1	$669	$2174	
The 5th Bridge	A-1	Single	BIM Coordinator	100	1	$729	$9113	$11,286
	A-2		Intermediate	26	1	$669	$2174	
The 7th Bridge	A-1	Single	BIM Coordinator	100	1	$729	$9113	$16,636
	A-2	Multi	Professional	26	1	$977	$3175	
			Intermediate	26	2	$669	$2174	
The 8th Bridge	A-1	Single	BIM Coordinator	100	1	$729	$9113	$13,461
	A-2	Multi	Intermediate	26	2	$669	$2174	
The 6th Tunnel	A-1	Multi	BIM Manager	30	1	$873	$3274	$17,006
			BIM Coordinator	60	1	$729	$5468	
			BIM Modeler	120	1	$551	$8265	
Test Bed Bridge	A-1	Single	BIM Coordinator	100	1	$729	$9113	$9113
Railway Tracks	A-1	Multi	BIM Coordinator	100	2	$729	$18,225	$26,490
			BIM Modeler	120	1	$551	$8265	
Total							**$116,348**	
Total with 10% additional allowance							**$127,983**	

Table 3 illustrates the entire cost estimates for BIM implementation in this study. As can be seen, the total amount of the cost to build a BIM is about $116,348. This is based on the type and process of works that are delivered from eight engineering firms. Man-hours and the number of labors are also identified by the experts in engineering firms. Daily fees for the BIM workers and professional engineers are published by the national government. The authors would like to note that this estimate is a relatively conservative measure as the calculation is based on the assumption that if the supplied BIM is detailed enough to finish the entire construction process, which is not the usual case in reality. Therefore, a 10% of allowance was added to provide any margins that may increase the cost in the BIM construct. As a result, the total cost estimate for BIM utilization in seven projects is about $127,983 with the marginal 10% allowance.

4.2. Benefit Estimate

To calculate benefits that come from using a BIM in this case, the authors closely searched how much reworks in terms of planning and construction have occurred as described in Table 2. After that, the authors calculated the additional costs that aroused due to the reason that the BIM was not implemented. These costs are relatively easy to be prevented if the constructed BIM was used for model checking during the beginning of construction stage. Because the eight engineering firms did not implement BIM, errors in Table 4 occurred and these are simple processes if model checker function in BIM was used beforehand. In addition, the authors divided benefits into two sections: benefits during BIM work and benefits during construction. In some cases, because drawing check was not done appropriately, rework did happen even in 2D drawing process and for that reason, increased construction fees were observed as well. In other words, a simple BIM work could have significantly reduced reorders in both drawings and construction.

Table 4. Total possible benefits that could be saved during BIM work.

Project	No. of Labor	Level	Man-hour	Daily fee	Estimates
Incurred Reconstruction Costs Based on Redrawing Orders					
Estimates = (No. of labor) × (Man-hour/8 h) × (Daily fee based on level)					
The 1st Bridge	1	Manager	40	$650	$3250
	2	Coordinator	160	$420	$8400
	1	CAD operator	80	$220	$2200
Total redraw benefits that could be saved if BIM was implemented beforehand					$13,850
Incurred reconstruction costs based on re-dimensioning orders					
Estimates = (No. of labor) × (Man-hour/8 h) × (Daily fee based on level)					
The 1st Bridge	2	CAD operator	24	$220	$660
The 5th Bridge	1	CAD operator	16	$220	$440
The 7th Bridge	2	CAD operator	40	$220	$1100
The 8th Bridge	2	CAD operator	32	$220	$88
Total re-dimension benefits that could be saved if BIM was implemented beforehand					$3080
Total benefits that could be saved if BIM was implemented beforehand					**$16,930**

Table 4 illustrates the total possible benefits of using a BIM to fix the redrawing and re-dimensioning errors. This cost is purely for BIM work, meaning that the associated construction costs need to be estimated separately. As can be seen, the 1st bridge project demanded four experts with 35 days of work, resulting in about $13,850 additional costs in redrawing orders. In terms of re-dimensioning orders, about eight experts with 14 days of reworks were placed resulting in about $3080 extra fees. As a consequence, the total incurred costs that could have been prevented if BIM works was carried out at the planning and design stage is about $16,930.

Because of the above rework orders, there have been reconstruction orders as well. To properly estimate the associated costs in reconstruction orders, the authors divided reconstruction into two phases: labor costs and material costs. Because reconstruction involves a number of multiple processes, it is relatively hard to precisely capture all the associated works and calculate the costs. Therefore, the authors decided to simplify the associated costs of reconstruction into two. In addition, because this estimate is based on just the physical amount of labor and materials, delayed construction due to rework needs to be inclusive. It means a risk in delinquency for the entire construction process should be calculated to properly reflect all the associated risks that incurred because of reconstruction orders.

As can be seen in Table 5, the total amount of labor fee incurred by reworks in bridges 1, 7, and 8 cost about $71,417 and the total amount of associated materials fee is about $78,139. As a result, the total amount $149,556 could have been unnecessary if BIM was utilized at the beginning of the construction stage and no reworks were placed. If so, minimal errors such as interferences and mismatches could be easily replaced before construction, making it much less costly and require less time to finish the work orders.

As mentioned earlier, to properly capture the benefits that a BIM could bring to the case, delayed construction days should be considered as well. Because of reorders in drawings and construction, there have been delays in the entire construction schedule. However, as the construction process does not occur independently, precisely capturing the delayed schedule due to the reorders is oftentimes a very difficult task. The authors have reviewed all the construction schedules and daily notes on the site, but it was impossible to pinpoint the delays that appeared to be responsible because of the above reorders. Therefore, the authors decided to implement liquidated damages instead.

Table 5. Total possible benefits that could be saved because of avoided reconstruction.

Projects	Errors	Solution		Estimates
The 1st Bridge	Retain wall and bridge interference	Rework		Estimate = (Volume) × (Unit fee)
The 1st Bridge	Girder and column level mismatch	Rework		
The 7th Bridge	Site elevation and drawing mismatch	Rework		
The 8th Bridge	Girder and column mismatch	Rework		
Labor fee estimate because of reconstruct				
Projects	Construction	Unit fee	Volume	Estimates
The 1st Bridge	Retaining wall	$47	1016M3	$47,752
The 7th Bridge	Sound-proof wall	$40	540M3	$21,600
The 8th Bridge	Concrete casting	$93	22.2M3	$2064.6
Subtotal				$71,416.6
Material fee estimate because of reconstruct				
The 1st Bridge	Retaining wall	$3	1016M3	$3048
The 7th Bridge	Sound-proof wall	$139	540M3	$75,060
The 8th Bridge	Concrete casting	$1.4	22.2M3	$31.08
Subtotal				$78,139.08
Total construction fees because of rework				**$149,555.68**

In general, the construction industry in Korea includes the maximum of 15% of the total construction costs as liquidated damage, and the maximum legal delay is up to 300 days. It means the liquidated damage is calculated based on 0.05%/day, and if there is any delay in construction schedule, 0.05%/day could be applied to calculate the liquidated damage. In this case, because capturing the precise delay due to the errors is a hard task, the authors calculated an estimate in terms of sensitivity of liquidated damage. If redrawing and reconstruction could have generated a month delay in construction schedule, then 1.5% of the damage could be added to the total costs. In other words, if the BIM was implemented and could have captured all the errors defined in the previous calculations, then a 1.5% liquidated damage could have been saved in a month, reducing the risk of construction uncertainty. Therefore, 1.5% could be regarded as benefits of using a BIM in this case.

Table 6 illustrates possible liquidated damage based on different lengths of delays. Since the cost of this study only involves cost for each error, liquidated damage is applied only to the errors costs that are covered in this study. This may be a very conservative approach in calculating opportunity costs. However, to enhance the validity of the research, the authors decided to include liquidated damage to rather smaller areas, not to the full extents in construction costs. As can be seen, a month delay could increase about $2500 in liquidated damage and a 3-month delay could make the total costs up to $173,978. This means if the BIM was utilized at the beginning of planning and design, then the range of savings in liquidated damage could be $2500 in a month to $7492 in three months.

Table 6. Liquidated damage based on different length of construction delay.

Delay	Initial Costs	Damage %	Liquidated Damage	Total
+1 month delay	$166,486 ($149,556 + $16,930)	+1.5%	**$2497.3**	**$168,983.3**
+2 months delay		+3.0%	**$4994.6**	**$171,480.6**
+3 months delay		+4.5%	**$7491.9**	**$173,977.9**

4.3. Benefit–Cost Analysis

Based on the three estimates, a BCA can be conducted. The cost can be identified as where BIM was utilized in planning and design stage. The total upfront costs required to provide a BIM for seven projects were $116,348, and if a 10% margin is added, then the cost goes up to $127,983. This is the necessary costs to construct a BIM to fix the errors in seven projects of the site. On the other hand, the total costs required to fix the errors in seven projects were $166,486. This can be regarded as the benefits of using BIM because if BIM was implemented then the associated errors would have been fixed easily.

In addition, because of these errors, there could have been delayed construction and this risk was calculated based on the liquidated damage. If 12 errors have caused a one-month delay, the liquidated damage would be $2498. In this extent, the total benefits could be regarded as $168,984 to $173,978, depending on the length of delayed construction. If the delay is anticipated for two months, then the liquidated damage moves up to 3.0%, which in turn provides about $5000 in benefits. A 3-month delay is therefore about $7500 in benefits. In this extent, the benefit–cost ratio can be estimated as 1.32 with a one-month delay and 1.36 with a three-month delay. Table 7 illustrates the final result.

Table 7. Benefit–cost ratio based on different liquidated damage.

BIM Cost	Design Rework Benefits	Construction Rework Benefits	Liquidated Damage Benefit	Total Benefits	B/C
$127,983 (10% allowance)	$16,930	$149,556	$2497.3(1.5%)	$168,984	**1.32**
			$4994.6(3.0%)	$171,481	**1.34**
			$7491.9(4.5%)	$173,978	**1.36**

5. Conclusions

This study is intended to capture possible financial benefits that a BIM could bring to a real project. Although the railway test bed constructed a BIM for design, it was not applied into its construction process, and the authors were successful to identify 12 errors that could be solved if BIM was implemented at the beginning of construction phases. Similar to the previous studies, adopting only surveys and interviews with the experts could have provided an in-depth observation in BIM application. This study, however, has tested a real-world example that could be benefited from BIM utilization, and this could be regarded as the difference compared to other previous studies.

All the 12 errors are relatively simple ones that could be detected if the BIM was adopted. Using a model checker or model reviewer, structural interferences, dimension mismatch, and dimension errors can be easily resolved in the BIM environment. However, because the project did not apply any BIM environment during construction, a number of reworks were carried out in two types, reworks in design and reworks in construction. Eventually, these two created additional costs and risks.

It means that although this study is not purely realistic, it indeed is founded on a real project. As mentioned earlier, all the experts from eight engineering firms have agreed that if the BIM was supplied at the beginning, then the 12 errors and associated costs could have reduced significantly. It means the use of BIM at the construction stage could have played more important roles in cost reduction and eventually risk management as a whole.

A benefit–cost ratio over 1.3 may sound too promising, and it does not guarantee all the projects using a BIM will enjoy the same benefits. Nonetheless, providing an alternative perspective that could suggest a foundation in benefits of using a BIM may enable a new opportunity for future applications. BIM was introduced less than 40 years ago. If we are to judge whether the success of using a BIM in construction industry, then shouldn't we have more diversity in real cases? More empirical studies should be followed to robust the findings in this study. In addition, not only for architectural projects, but some other projects in urban and infrastructure scale should be tested to provide a more holistic outcome in this area.

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